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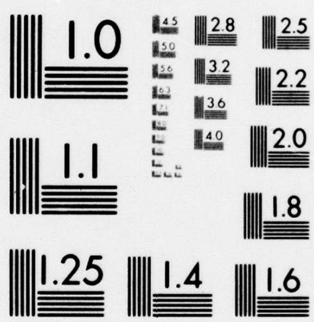

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6) HUMAN FACTORS IN THE DESIGN AND EVALUATION OF AVIATION MAPS

by

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PREFACE

Man has no natural sense of direction. While travelling, he has to rely on vision and his other senses, and on learning, memory and reasoning, to maintain orientation. Flying long distances over unfamiliar terrain at fast speeds in all kinds of weather overloads human capabilities, and an unaided man is likely to become lost and to remain lost. To navigate during flight, he must supplement his directly sensed information with aids, such as compass, radio and map. These provide him with a frame of reference, and allow him to think ahead and to plan and follow a route. However, the information from these aids has to be perceived, decoded and interpreted by the user. Consequently, the methods for displaying it determine its usage, and must overcome the limitations which led to the need for aids.

Cartographers have traditionally been responsible for the design of maps. Recently, applied psychologists have become involved in map design because of their general knowledge of man's abilities and limitations, and their particular knowledge of the principles of information display. Both the cartographer and the psychologist seek to ensure that aviation maps fulfil their intended functions as effectively as possible. To achieve this, the psychologist has to acquire more knowledge about cartography than the typical map user possesses, and more knowledge of map usage than the cartographer normally has. In addition to fulfilling his own role, the psychologist may try to apply the broad knowledge which is necessary for his own tasks, to see that no relevant opinions are ignored when recommendations for map designs are made.

Modern technology has had four main effects on aviation cartography. Firstly, automation, digitisation, and process printing have increased the pace and flexibility of map production. Secondly, developments such as moving map displays and electronically generated map displays are changing the modes of presentation of cartographic information in the cockpit. Thirdly, the introduction into the cockpit of radar displays, infra-red displays, image intensification devices, and low light television displays bring new requirements for associated cartographic support. Fourthly, new aircraft and new operational roles influence the ways in which maps can be used or are required to be used.

No recommendations in human engineering handbooks have been compiled specifically from maps or for maps. Maps are probably the most complex visual information displays within the cockpit, but the validity of most standard human engineering displays recommendations has been established only for much simpler material. It is therefore important to check whether these recommendations for displaying information apply to maps, and, if they do not, to formulate valid recommendations for maps, perhaps after devising new assessment methods. In order to conduct human factors research on maps it is necessary to have independent control over each variable. This implies professional cartographic support. If a single variable is altered, any resulting effects may owe more to the interaction between that variable and other cartographic factors than to the variable itself. Also, the uniqueness of each geographical location makes it difficult to prove that findings are general, and are equally applicable to other map series or to other geographical regions.

Most well-established psychological principles of visual perception have been derived from simple material and not from material as complex as maps. Certain cartographic concepts, such as visual balance, have no equivalents in psychological parlance. Much of the psychological work in cartography has been done by geographers or cartographers who have read some psychology, rather than by psychologists with a knowledge of maps.

Many principles for portraying information on aviation maps and many methods for evaluating them may apply to other maps too, whereas evidence on the tasks and skills of map users and on the effects of the work environment on map reading may be specific to aviation maps. Users and cartographers tend to answer questions about map usage in terms of their past experience, so that novel uses of existing maps, and different applications of new map forms, may be overlooked.

In aviation, the concept of charts is as familiar as that of maps. Common distinctions are that a chart is aeronautical and a map topographical, that a chart is for navigation and a map need not be, and that a chart is annotated, used and discarded but a map is more permanent. Generally, throughout this volume, the concept of maps is used to include both maps and charts.

This text seeks to gather together and describe the whole range of actual and potential human factors contributions to designing, using and assessing aviation maps. On some topics, the authors have had recourse to principles or guidelines, and in the absence of definitive evidence, it has been possible to do little more than define problems. However, the text as a whole, together with the checklist, may provide useful foundations on which others can build.

The text makes specific references to the black and white figures, but not to the colour plates. This is partly because such references would be too numerous, but mainly because the colour plates, with the notes about them, are also intended to be viewed in their own right as a set which collectively illustrates many of the points discussed.

In preparing this volume, the authors have benefited from discussions and correspondence with many colleagues in psychology, cartography and aviation. Their help is gratefully acknowledged, although the responsibility for the text, and for any errors or omissions in it, lies with the authors. The sponsorship by the Aerospace Medical Panel of AGARD, and its forbearance during the writing, are acknowledged with thanks.

Human factors research on maps at the Royal Air Force Institute of Aviation Medicine, is sponsored by the Deputy Director (Nav) (RAF), and receives cartographic support from the Mapping and Charting Establishment, R.E., under the direction of the Director of Military Survey, UK Ministry of Defence: their contributions to this work are also acknowledged with thanks. The brunt of the clerical and typing effort was cheerfully borne by Mrs M.Fawcett and Miss N.Wakely.

CONTENTS

LIST OF FIGURES

LIST OF COLOUR PLATES (Appendix)

CHAPTER 1

INTRODUCTION

1a THE DEVELOPMENT OF AVIATION CARTOGRAPHY

Aviation cartography traditionally began with Moedebeck's[1] paper, based on his experience as a balloonist, suggesting how maps could be annotated to aid aerial navigation. For the next twenty years he continued to argue the case for special aeronautical maps. His pioneering work was reviewed at the time by Peucker[2], and more recently by Ristow[3]. The latter, and Meine[4,5], have compiled historical bibliographies of, and introductions to, aviation cartography, each with nearly 1,000 references.

Attempts to construct the first aviation maps were begun in Europe before the First World War, largely under the influence and guidance of Moedebeck. The first true air map is generally considered to be a 1:300,000 chart published in Germany in 1909 under the sponsorship of the German Aeronautical Society. Shortly after, in 1911, the first meeting of the International Commission on Aeronautical Charts was held in Brussels with representatives from Austria, Belgium, France, Germany and the United Kingdom. There was little interest in aviation maps in the United States before World War One. The main American interest dates from papers by Whitaker[6] and Woodhouse[7], the former stating the need and the latter describing four types of European aeronautical map.

Early writings on the provision of aviation maps recognise the magnitude of the effort required to compile them, and acknowledged the need for support from official Government mapping agencies (Moedebeck[8]). For economic and practical reasons, early aviation maps were adapted from existing land maps by overprinting additional aeronautical information. A few specially designed aviation maps were produced, such as the air map of Long Island prepared by the Aero Club of America in 1911 and the map produced by Cliff and Gross for the 1912 Aerial Derby around London, but these maps were largely experimental in nature. When World War One began, only France had completed a considerable number of sheets of a basic map.

For most aviation needs, overprinting aeronautical information on standard maps served as a short term solution, in lieu of special purpose sheets. Despite the resulting clutter, overprinting standard maps continues to provide a cost-effective temporary solution to many aviation mapping problems, particularly at large scales with numerous sheets.

It could be argued for early aviators, as it is today for helicopter pilots, that because of their low flying speeds their requirements for topographical information were not sufficiently different from those of the land map user to warrant speical-purpose base information. Nevertheless, overprinting standard maps was probably a more acceptable practice then than it is today. Despite this, much early literature did call for innovative thinking in map design to meet the needs of the air user. Regarding the problems of balloonists at night, Moedebeck[8], wrote "the chart (for the night balloonist) should not only concern itself with optical data, but with acoustic data as well. The rustling of the trees in the forest, the roar of the surf, big city noises, the rumbling and whistling of trains, the noisy din of industrial plants, the cries of domestic animals in the villages; all these sounds make it possible in conjunction with the map to orient the course of a free balloon during night flights". Later, Lees[9] observed that "maps exist at present for those who travel on land or sea; now a start is to be made on maps for those who travel by air, and these maps must be based, not on the conventions, but on the requirements of the airman". He pointed out that the aviator's view "is more or less vertically downwards – he does not require much in the way of names, but he does want the characteristic geographical features and all artificial features of special value as guides to stand out clearly. Shape is of special value to the airman". The design of an air map must therefore "be a logical one, controlled by the values which the aviator places upon the various objects seen from his machine. The object must be to obtain a map which shall be clear, which shall be a fairly good picture, and which shall give the objects on the ground a value which the aviator places upon them" (Ristow[3]). Many of the above points still sound very familiar today.

Standardisation of specifications was from the beginning a major international issue, as it continues to be. Lees[9], reporting an International Agreement on Aeronautical Maps and on the colours, symbols and scales to be employed, criticised some of the initial proposals and suggested what should be shown and how it should be depicted, including detailed proposals on colour coding. Many issues raised by Lees, such as the merits of hill shading and the choice of layer tints in depicting terrain, are still disputed today. Other issues raised in the 1920s included the problem of handling charts in a confined cockpit and the merits of photo mosaic maps for air navigation compared with conventional line maps. Strip maps were popular during the 1920s because of the difficulty of handling large charts. In the late 1920s, more flying came to be done away from established air lanes, and strip maps began to lose favour, to be replaced by sectional charts. Aerial photographs were used successfully during the First World War, when time did not always permit

preparation of line maps. After the war, production of photo maps continued in the United States and aroused considerable interest for a few years, until experience proved them to be impractical and inferior to line maps.

Whereas Duval[10] deplored the lack of progress in preparing aviation maps to agreed international specifications, during the next few years substantial effort was expended in compiling air maps, so that Miller[11] while presenting his own experimental map, was able to list 39 air maps, mostly produced by official mapping agencies, ranging in scale from 1:31,000,000 to 1:14,400 classified into five groups according to envisaged uses. Commercial publishers began to show interest in aviation maps. In 1928, Rand McNally's air trail maps of the United States were first published. Soon afterwards Jeppesen Air Charts, frequently revised, began to appear (Rosenkrans[12]).

The 1930s also saw the development of maps designed to be legible under artificial cockpit lighting at night. Burton[13] reported the production of an experimental strip map by the US Air Corps in 1934 with a night flight map printed in red on the reverse for use under artificial light. At the same time maps were in production in the United Kingdom that avoided use of red map colour for important information so that legibility would be ensured under red cockpit lighting used at night. At 1:250,000 and 1:500,000 scales these maps, known as the rearmament series (GSGS 3957 and 4072), emphasised certain topographical features useful for air navigation and omitted information superfluous to air requirements.

The Second World War brought demands for vast quantities of aviation maps, for worldwide coverage at uniform scale with agreed international standards and conventions, for maps intended for Joint Service use, and for maps compatible with instrument and radio navigation (Harvatt[14]). In 1943 the important 1:1,000,000 scale World Aeronautical Chart was published by the US Air Force Aeronautical Chart Service with international co-operation. Manuals on how to use maps proliferated, and Ristow[3] mentions a few of them. Little of the work on aviation cartography during the Second World War was reported at the time, and the numerous retrospective accounts of it are often anecdotal rather than scientific. The literature, however, often first raised issues subsequently studied in more detail, such as the relationship between maps and air photographs, (Lobeck and Tellington[15]) and the potentially misleading association between the aesthetic appearance and the scientific authenticity of maps. An ugly map is less likely to inspire confidence (Wright[16]). Aviation maps were already being criticised, in the same terms and for the same reasons as they are criticised today, for failing to meet or to understand the needs of the users (Chichester[17]). One wartime development was the introduction of fluorescent printing inks for use under red, amber or ultra violet cockpit light (Pinson[18]; Armstrong[19]). Fluorescent maps were used extensively by US military aviators but not adopted by the Royal Air Force, largely on medical grounds.

The years immediately following the Second World War saw the setting up of the International Civil Aviation Organisation (ICAO) whose Aeronautical Charts Division became responsible for standards and specifications for international chart series adopted by ICAO. About 1950 there was a resurgence of interest in, and research on, many aspects of aviation cartography. The advent of high speed jet aircraft and of instrument and radio navigation brought about new specialist needs that could not be met by general purpose charts such as the aeronautical chart. A variety of new products appeared including planning, radio facilities, approach and landing charts, in addition to conventional route charts. Korean War experience showed that there were many inadequacies in these products. Particularly, the proliferation meant that too many charts needed to be consulted to obtain the necessary information, whereas the general purpose charts were too cluttered for ease of reading. These problems stimulated the US Office of Naval Research in 1951 to place a human factors research contract with Dunlap and Associates to conduct a systematic analysis of the problem. A series of research reports followed.

Criticisms of maps then current were used to make proposals on the development of improved aids for operational roles (Kishler, Waters and Orlansky[20]; Dorney, Waters and Orlansky[21]). Design principles were claimed to improve charts when applied to a specific aircraft mission (Bishop, Water and Orlansky[22]; Waters and Bishop[23]), and psychology, among other disciplines, was mentioned as providing guidance on the depiction and choice of cartographic information (Waters and Orlansky[24]; Schreiber[25]). Attempts were made to evaluate charts experimentally by assessing their adequacy for their intended purposes (McGill and Cain[26]), by comparing new charts with those which they would replace (Murray and Waters[27]; Murray[28]), and by studying the associational value of aeronautical chart symbols (Koponen, Water and Orlansky[29]).

The requirement to produce maps for long range high speed altitude navigation was the focus of most of this research. Many experimental maps preceded the eventual production of the 1:2,000,000 jet navigation chart, and two of these, the US Navy Experimental Chart XDA and the USAF Experimental Jet Chart XJN were evaluated in the Dunlap studies. Throughout this period, the US Aeronautical Chart Service, renamed the Aeronautical Chart and Information Service in 1951, and the Aeronautical Chart and Information Centre in 1952, played a major role in research and development of air maps, as it still does.

In The United Kingdom analytical studies of map design began at the Roayl Air Force Institute of Aviation Medicine with an investigation of the problems of map reading under red cockpit lighting, stimulated presumably by the large amounts of night flying carried out by the Royal Air Force during the Second World War. Comparisons of existing maps (Whiteside[30]) led to modification of map symbols (Whiteside and Roden[31]), and to flight trials of an experimental monochromatic map (Ruffel Smith and Whiteside[32]). The red lighting requirement, the source of major cartographic

problems, persisted, although the gains in dark adaptation under red light conditions were small, as reported in the original wartime studies comparing red light with yellow and green (Pinson[18]), with white (Anon[33]) or with ultra violet (Armstrong[19]).

Laboratory studies of colour coding and typographical legibility under low level red illumination were carried out shortly afterwards at Tufts College, under the sponsorship of the Wright Air Development Centre (McLaughlin[34]; Crook, Hanson and Wulfeck[35]; Crook, Hanson and Weisz, (a)[36] and (b)[37]). Several experimental charts and detailed design recommendations resulted from this work. Reviews of this research and earlier work are available (Wulfeck[38]; Chapanis[39]; Crook, Hanson and Weisz[40]). Since the research, attitudes towards red cockpit lighting have changed, and many aircraft are fitted with white instrument lighting, although red light legibility considerations continue to influence the specifications of many map and chart series.

Other research contracts sponsored at the time by the Wright Air Development Centre were carried out by the Ohio State University Mapping and Charting Research Laboratory (MCRL). Miller[41] considered scale and legibility factors, and Miller, Rowell and Hitchcock[42] examined methods of relief representation. MCRL continued to publish research reports throughout the 1950s. Unlike the Tufts College work which ended in 1954, the MCRL research was primarily cartographic, and carried out by cartographers rather than human factors specialists.

European developments suffered through the reduction of Italian and German influences. It was not until 1955 that Germany resumed the publication of aeronautical charts. In the UK, Freer[43] drew attention to the need for greater simplicity and generalisation in approach and landing charts, but much contemporary European literature was concerned with polar and global air navigation (Ramsayer[44]). In 1956, Meine of Bundesanstalt fur Flugsicherung began publishing articles on aviation cartography, mostly descriptive or bibliographical in nature. Two exceptions were his papers on problems of colour and relief representation with particular emphasis on aeronautical charts (Meine[45,46]).

Electronic developments played an important role in aviation cartography during the 1950s. Special navigation charts for DECCA GEE and Loran radio aids were produced in increasing quantities, and as early as 1950 the concepts of capsule charts reproduced by film or by electronic means on a portable pictorial computer had been advanced (Kay[47]), and also those of the roller map display (Ruffell Smith[48]). Hartman[49], Sperry[50] and Poritzky[51] all described working pictorial computers and automatically moving position indicators, and Poritzky[52] described a similar device with a map projected from 35 mm film. These developments, as Dennis[53] pointed out, resulted from the need for increased automation of navigation functions in the high workload high speed jet aircraft. However it was not until the early 1960s that roller map displays were fitted in quantity to operational aircraft.

The problems of radar interpretation and map aids were the subject of research by psychologists in the US Air Force Personnel and Training Research Centre in the late 1950s (Daniel et al., (a)[54] and (b)[55], Lichte et al.[56,57]; Lichte (a)[58] and (b)[59]). These studies did not lead to changes in map design but merely investigated the factors in comparing radar with conventional maps. Modification of map design to aid radar navigation were first proposed by cartographers at MCRL (Angwin[60,61]). Slope zone shading of relief was proposed and illustrated, as a means of increasing the correlation between the radar returns and the cartographic portrayal of relief.

In the late 1950s, research effort began on the problems of low level high speed flight. Completely fresh thinking on the cartographic problems was required. It was found necessary to develop maps at 1:1,000,000 and 1:500,000 scales. Frequent changes of sheet had to be avoided, and new methods of representing relief and topographical detail were required to assist rapid terrain appreciation (Harvatt[14]). Research papers, produced by MCRL, made detailed design proposals (Miller[62], Angwin[63], Angwin and Belkin[64]). In 1959, the first sheets of the US 1:1,000,000 operational navigation charts (ONC) were produced, shortly followed by the Royal Air Force 1:1,000,000 topographic navigation chart (TNC), using the same sheet lines. A new method of depicting terrain by layer tints was used and maximum terrain elevations were employed. At about the same time, the 1:500,000 scale US pilotage charts (PCs) and the corresponding UK topographic tactical charts (TTCs), were issued. These series used a conventional layer system, maximum elevation figures and hill shading to accentuate relief shape.

The human factors problems associated with the provision of maps for high speed low level flight began to be studied from 1963 onwards by McGrath and his colleagues at Human Factors Research Incorporated (McGrath and Borden[65]). This programme continued throughout the 1960s. New methods and techniques were developed and proved, particularly the use of ground simulation of high speed low level flight, but a major constraint throughout the programme was the lack of professional cartographic support. The work of Lewis at the Defence Research Medical Laboratories in Canada marked the beginning of helicopter studies, and of the recognition of the special cartographic requirements for low speed low level navigation (Lewis[66]). In the early 1960s the development of projected map displays led to a requirement for professionally produced cartographic film strips. The pioneering work on this topic was largely done by Honick of the Royal Aircraft Establishment, who was probably the first to recognise the need for specially produced maps to circumvent the limitations of microfilming (Honick[67]). From discussions begun in 1965 NATO standardisation evolved for 1:1,000,000, 1:500,000 and 1:250,000 scale topographical maps with worldwide coverage. In the case of the last map, this was the first time worldwide coverage at this scale had been attempted.

Much of the activity in aviation cartography during the 1960s, was covered by two JANAIR Symposia[68,69], both edited by McGrath. The former included a paper by Burton identifying themes requiring future research in aeronautical

charting, many of which were primarily human factors problems. This influenced the initiation of a systematic programme at the RAF Institute of Aviation Medicine studying problems in aviation cartography with cartographic support supplied by the UK Mapping and Charting Establishment. This support included the provision of material, using cartographic production and printing facilities, specifically for human factors experimental studies. Hopkin[70] described the human factors principles to be incorporated in an experimental 1:250,000 scale map sheet, intended to test the applicability of those principles to maps.

1b THE SEPARATE DEVELOPMENT OF HUMAN FACTORS

Human factors as a discipline owes little to cartography for its development. It has progressed to a stage where factual handbooks present human factors knowledge by compiling and distilling the findings of a large number of experimental studies. Many of these studies have been related to aviation problems, particularly in ground control systems, but the number of definitive findings derived from original studies on aviation cartography, or indeed on any cartography, is negligible. While detailed recommendations to ensure the effectiveness of many kinds of information display can now be made from existing knowledge, the applicability of these display principles to maps has scarecely been established. Human factors has shown remarkably little interest in maps. Although numerous human factors studies relevant to maps are mentioned in this volume, comparatively few have been conducted by those with professional human factors knowledge and most are the work of geographers, cartographers or those trained in other disciplines, who have taken an interest in human factors problems and read some of the applied psychological literature.

The origins of human factors include industrial psychology between the two World Wars (Tiffin and McCormick[71]) and early studies of selection, training and individual differences (McFarland[72]). Techniques such as time and motion studies (Barnes[73]) were developed. Before the Second World War the main emphasis was on the design of controls and workspace to optimise efficiency as measured by output. During the Second World War operators encountered difficulties in interpreting new information displays, particularly radar, with the result that the need to match information with human capabilities was acknowledged. From then on, findings accumulated on principles for the presentation of visual information: its layout and coding, its collation and processing, its optimisation for various tasks, its discriminability, legibility and readability, and its influence on errors and delays. General display principles were not usually sought but were derived when independent studies produced similar findings. These principles covered display design including coding conventions and alphanumerics, workspace design including anthropometric data and effects of the physical environment, control design, and man-machine systems including communications (Morgan et al.[74]). All these findings originated in far simpler perceptual material than topographical maps.

Attempts to build perceptual theories led to much experimental work using simple forms to elucidate the principles of perceptual structuring and organisation and the resulting theories and models were couched in psychophysical (Attneave and Arnoult[75]) or neural (Blackwell[76]) terms. This produced few established facts, but many theories. These studies tested theoretical hypotheses about forms (Gibson[77]). Forms were normally degraded by a variety of means, so that they were viewed under near threshold conditions under which an increased proportion of errors in detection, in discrimination, recognition or identification might provide insight into the mechanisms involved. These theoretical studies deliberately employed forms under conditions where visual structuring was just possible. Practical applied studies were concerned with conditions well above threshold under which few errors of operational significance might occur. This gap between theoretical and practical studies was seldom bridged. Certain studies of texture gradients (Gibson[78]), of pattern perception (Hake[79]), and of form perception (Hopkin[80]) did have both theoretical and practical aims in view and the concepts could be applied to practical problems. Ironically, much of the most influenctial work is now thought to be wrong by its originator (Gibson[81]) on the grounds that the distinction between 2-dimensional and 3-dimensional perception, implied in studies of form perception, is false.

Recently rekindled interest in mental maps and images (Gould and White[82]) has centred on man's notion of his environment and of himself in it. Mental maps and images have long been studied as cues to geographic orientation (Ryan and Ryan[83]), and research continues on how primitive people navigate (Lewis[84]). Tolman[85] studied the processes involved in learning cognitive maps, and Piaget and Inhelder[86] have studied how human notions of representational space evolve. For both of these studies mental maps are a tool to understand learning processes better, and cartographic applications were not envisaged. Occasionally map reading processes have been examined not to learn more about them directly but because they are claimed to be analogous to other thought processes and thus to provide insights about them (Barlett[87]). Griffin[88] defined a map as a graphic representation of a schema by which he meant that ideally maps should conform to mental images. The study of mental maps should therefore provide information on the content and coding of cartography, but only for such specialised purposes as the production of maps for the blind have mental maps and images being studied to determine the thought processes of map users, in order to complement those thought processes by suitably designed maps (Leonard and Newman[89]; Gill[90]). Some clinical implications of distortions in mental maps have been considered in a comprehensive survey of human spatial orientation (Howard and Templeton[91]) and more recently mental maps have been related to environmental psychology by Stea and Downs[92], but neither of these approaches includes the cartographic implications.

In the psychological literature, geographic orientation and its associated mental processes have been treated primarily as human limitations rather than as abilities to be optimised and complemented. A general criticism of information display design, applicable to maps and in many other contexts, is that the display cannot be optimally matched to human

abilities because the relevant abilities have never been adequately defined and described. Although in aviation cartography and elsewhere the needs and skills of the users are frequenly mentioned in relation to display design, in practice the emphasis tends to be on the needs of the task and of operational requirements rather than on the needs of the man.

The application of human factors knowledge to aviation problems often appears to be erratic. For example certain cockpit instruments and warning indicators have been studied in depth, to the extent of precise recommendations on the detailed design of instrument dials (Fogel[93]), yet many pilots still enter cockpits carrying voluminous job aids, including manuals, instructions, meteorological information, maps, and charts, and find no adequate provision to store them, to classify them or to retrieve them when they are needed. Many of these job aids are poorly adapted to restricted cockpit environments.

Two main kinds of psychological evidence might be expected to assist the design of aviation maps. On the one hand are studies of the mechanisms involved in the perception, structuring and processing of visually sensed data, and on the other are applied studies of how man uses this information to perform tasks. However, studies of the former type have generally been conducted to test theories, and studies of the latter type have seldom been interpreted in theoretical terms. There are therefore no immediate practical answers to such questions as how the Weber-Fechner Law on just noticeable differences should be used to derive a set of layer tints for maps (Jenks and Knos[94]), on how colour distortions might affect the visual appearance of maps with complex colour codings, or on how the cartographer's concept of visual balance (Robinson and Sale[95]) could be expressed in psychological terms. Although the Gestalt laws of perceptual structuring have been applied to the design of symbols for machine displays (Easterby[96]), no practical answer is available on their applicability to terrain depiction and to map generalisation.

Most potentially usable psychological concepts, tied as they are to perceptual theories and mechanisms, have proved difficult to relate to the simplest information displays, and can seldom be applied with any confidence to visual material as complex as maps. Sometimes psychologists have warned that findings may not generalise (Burt[97]); more often they have presumed that their findings are general or have failed to consider whether they are or not. Cartographers and geographers have believed that they are justified in discussing psychological findings in relation to cartographic problems because the findings have been presented as truths unhedged by conditions (Robinson[98]). On the rare occasions when the validity of applying human factors recommendations to maps has been questioned and tested, the usual outcome has been to demonstrate that much of the evidence on display design principles does not apply to maps (Bartz[99]; Taylor[100]). As a consequence most psychologists have started from scratch in approaching cartographic problems whereas cartotraphers have tended to presume the relevance of psychological findings. A crucial problem for the psychologist is whether maps can be classified as information display at all, in the sense that standard recommendations for displaying information apply to them.

Some human factors data is available derived from research on maps. Wulfeck et al.[101] summarised recommendations on the design of maps for use under red cockpit lighting and low level ambient light. Ekman et al.[102], and others, made recommendations on the design of symbols for representing quantitative information on maps. Christner and Ray[103] studied symbol and background coding effects on map reading performance. Relevant research in related areas includes that of Crook[104] on printed materials, and of Baker[105] on grids on PPI displays. However, the quantity of such research is very limited and handbooks, such as that of McCormick[106], have to rely largely on findings from other complex visual displays with unproven relevance to maps.

From the point of view of human factors, the concept of displays does not usually include or refer to maps. As late as 1960, Gordon[107] discussed the applications of human engineering to navigation equipment without mentioning maps. Taylor and Hopkin[108] considered that human factors principles had been applied so rarely to the design of aviation maps that it might be profitable to verify which standard recommendations for coding and displaying information applied to maps and which did not. Hopkin[70], advocating the application of human factors principles to map design, cautioned that the resulting changes in map design should not be assumed to be beneficial without empirical verification, and that the application of these principles was no substitute for adequate job analysis and surveys of user opinion. At the present time, therefore, the body of established fact on display principles for maps is much less than that for most types of display. Much work has still to be done to resolve simple fundamental issues.

There are several reasons for the neglect of maps by human factors. One is that map design has traditionally been the responsibility not of engineers or of psychologists who would view maps as one of several display types, but of cartographers who follow long established traditions and conventions for information portrayal. For many years conventional cartographic practices have proved adequate, if not optimum, but technical advances in recent years have forced cartography to become more inter-disciplinary in its approach. Another reason is that human factors experiments on maps are difficult to design because changes in any single variable have complex interacting effects on others, and are difficult and costly to arrange because skilled expensive cartographic support is essential to provide valid findings. Any human factors recommendations for portraying cartographic information which ignore a fundamental restraint implicit in map technology are not only valueless but imply naïveté or incompetence in the human factors workers.

Display design principles can be related to various psychological theories. Barmack and Sinaiko[109] assessed the relevance of theories of cognition to display design, and Singleton[110] considered the use of behaviour theory as a general approach to display design. Taylor[111] has successfully applied information theory to map design. Inevitably, the simpler the display the easier it is to judge the potential relevance to it of any theoretical taxonomy, particularly as a source of

insight and hypotheses. With maps, the value of a well established theory may remain uncertain, and the hypotheses it generates untenable. Not surprisingly therefore, psychologists who wish to test a theoretical issue or to study general perceptual laws never choose maps as their experimental material. Consequently, the vast number of psychological laboratory studies on vision have revealed nothing directly about maps at all, because maps are too visually complex to be selected to prove or disprove theoretical psychological issues. Practical psychological guidance on map design emanates from applied studies. While the problems described by Chapanis[112] in extrapolating from laboratory studies to practical situations still arise, non-cartographic laboratory material is so obviously different from maps that any generalisations from laboratory experiments are automatically made with extreme caution by psychologists, although others may be less aware of the need for caution.

Recently, a problem familiar in other human factors contexts has arisen with maps because of advances in display sensors and technology: for some reason the man is unable to use the information on his displays. Usually, this occurs when existing maps prove to be unsuitable for new purposes. For example they were never intended to withstand the processing required for projected map displays or to have radar information superimposed on them or to be used to interpret a collateral infra-red line scan picture. Sometimes essential information has been lost on the new display, sometimes it is present but the man cannot make sense of it, and sometimes the quantity or quality of map information has become inappropriate for its intended function. In such circumstances human factors knowledge of man's abilities and limitations may be used to specify a map which strikes a cost-effective compromise between operational demands, technical feasibility and financial resources. The aim of human factors is to seek optimum solutions to problems if these can be attained. Such a single-minded approach must be tempered by a willingness to achieve solutions which work, by an understanding of the requirements and constraints of other disciplines, and by a judicious appraisal of those compromises which are acceptable and of those which cannot be entertained because they would sacrifice too much in terms of efficiency, safety or practicality.

CHAPTER 2

THE PREPARATION AND PRODUCTION OF MAPS

2a SURVEY AND DATA COLLECTION

The procedures for gathering the original data upon which maps are based are not traditionally part of cartography. Human factors principles could be applied to processes such as surveying and aerial photography as to any other job. If they were, they would cover the application or ergonomic principles to improve the tools of the trade, and human influences on the surveying process such as errors in measuring angles and distances, and in data reduction. These topics are outside the scope of this volume, but their end product is not. The processes which determine the quantity and quality of information available for map production must be mentioned insofar as they limit the accuracy and content of maps.

Aviation has had a large impact on map production methods. Originally, data had to be collected by surveys on the ground, and the quality of information varied with accessibility of the terrain. Often the first surveys of a region were made by amateurs, and the accuracy of the results was variable and unpredictable; with aviation came photogrammetry, the making of maps from aerial photographs. This technique revolutionised map making by its greater speed, precision and coverage. To some extent the inviolability of political boundaries discouraged the uniform worldwide application of photogrammetry. Recently the extension of the technique to orbitting satellites has permitted, at least in principle, the uniform application of photogrammetric techniques to the entire surface of the earth, given the necessary international agreements.

A fundamental problem is that users tend to make deductions about the quality and accuracy of information on the map from its scale and appearance. The nature of the information that can be included on a map depends on the accuracy, completeness and recency of the survey and on the methods of measurement, collection and classification of data. The quantity and quality of surveys vary in different regions of the world. Discrepancies between different surveys often exist because of irregularities in the earth's shape or gravitational field. These may prevent accurate positioning of different survey areas in relation to each other. A survey may be suitable for producing large scale maps for infantry purposes but relative discrepancies between surveys may make them useless for determining missile system target data or for large scale aeronautical charting (Gammon[113]).

Methods of indicating the level of accuracy by coding on the map itself are rudimentary. Geodetical surveys are costly and lengthy, and there can be no such thing as a completely up to date chart. The timing of revisions may be related to the quantity of important information which has become out of date but is often determined more by financial constraints than by operational requirements. Maps may incorporate warnings about inaccuracy, such as a statement that relief data are inaccurate or an indication that the runway limits of an airfield are unknown, but it is not known how the user interprets or makes use of such guidance. Many other sources of inaccuracy inherent in cartography are not made explicit. These include the positioning of roads, railways and rivers in valleys, codings for widths of rivers, and positioning of place names. Map use is determined by the user's interpretation of accuracy which depends on the cartographer's success in conveying accuracy to him.

Producers of aeronautical charts rely to a great extent on reports from users to update the information on charts and to improve their accuracy. Users are encouraged to inform the map production agencies of any inaccuracies and useful changes of content. On some operational squadrons, aircrew annotate a master chart with amendments, and a member of the squadron is responsible for collating and forwarding these amendments.

Cartography must adjust to the amount of information available. It does so in two ways: a small scale map of a well mapped region can depict only a small proportion of the known information; a map of a poorly surveyed region at the same scale may show everything that is known even if it is of no practical value to the user. A complaint by users of aviation maps is that inconsistent criteria are used for selecting information, linked to the cartographer's need to ensure that the finished product shows something rather than nothing. Because cartography abhors a vacuum, desert regions for example may be portrayed in a way which implies that certain features, invisible from the air, will be seen. A claimed merit of the 1:250,000 scale Series 1501 Joint Operations Graphic is that according to its specification "unreliable areas are clearly marked, approximations are labelled or symbolised, and accuracies clearly defined" (Bennett, Hogg and Lockyer[114]).

It is necessary for another reason to be aware of the roles of photogrammetry and surveying before applying human factors principles to the portrayal of information on maps. Operational needs, or the needs of the user, may indicate that

certain distinctions between categories of information should be made, using different codings. Unless such suggestions conform to a distinction made in surveying or photogrammetry then they cannot be implemented, no matter what their merits. For certain aviation users, particularly in high speed, low-level flight, types of bridges could be separately coded on the map to facilitate the positive identification of each, but some of these distinctions require information which does not exist worldwide. Techniques are available and are being improved for the derivation of terrain heights and slopes from photogrammetric material, but the prime purpose of such material is still to provide absolute and relative positional information (Robinson and Sale[95]).

2b PROJECTIONS

A perennial mapping problem is still that of projection. Basically it is impossible to depict a segment of a globe on a flat piece of paper without incurring some distortional deformation. However it is usually impractical to use a globe directly because only half of it can be observed at once, and it is difficult to handle and store, difficult to make and reproduce and difficult to measure on and draw on. Therefore in practice projections are essential. The smaller the scale of the map, the more serious the problem of distortions become. Distortions affect the ability to make measurements from maps and the ability to correlate views of the outside world with the map. For large scale maps, used principally for visual navigation, the distortions are negligible, to the point where they can be ignored for visual correlation.

Numerous projections have evolved, depending on the needs of the users and on which information must be accurate and which need not be. Projections are used for navigation purposes because there is no angular deformation at any point on the projection but area scale varies from point to point.

A description of map projections in relatively simple terms has been provided by Kellaway[115] as an introduction to the subject. A more technical treatment of the subject by Maling[116] includes algebraic expressions for all the most important map projections.

In order to map the earth at a given scale it is necessary to know its size and shape. The study of this is geodesy (Bomford[117]; Maling[116]). Positions in space are recorded by co-ordinates which specify position in two dimensions. This principle is used on maps to designate any location by grid reference. A grid refers to the projection system being used. Thus the universal transverse Mercator (UTM) grid is used with a UTM projection.

The distinction between great circle lines and rhumb lines is important in cartography in determining what projection is appropriate. If any intersecting geometrical plane passes through a sphere the shape of the section of the sphere at the plane is circular. If the intersecting plane passes through the centre of the sphere, the radius of the circle is the same as the radius of the sphere. Such a circle is a great circle. If any two points on the surface of the sphere are selected, provided they are not the ends of a diameter, only one great circle can be drawn through them, and the shortest distance between the points on the surface of the sphere follows the arc of this great circle. As a result the shortest long distance aerial routes always follow great circles. Any great circle line, except those which coincide with the meridian over the equator, intersects every meridian at a different angle. A line which intersects every meridian at the same angle is the rhumb line or loxodrome. Over very short distances great circle and rhumb lines coincide for most practical purposes. Over very long distances, thousands of miles, the two diverge considerably. The great circle is the shortest distance, the line of sight and the path of radio signals but continuously varies in direction, whereas the rhumb line represents the same direction throughout but is longer in distance. (Fig.1).

The problem arises in selecting a suitable conformal map projection that either the great circle or the rhumb line or perhaps both must be depicted as curved. Originally aeronautical charts followed nautical ones in choosing projections, usually the Mercator projections, where a straight line on a map depicted a line of constant bearing (a rhumb line) but not the shortest distance (a great circle line). The reason was that it is easier for a navigator to travel along a rhumb line having constant bearing. He could draw a straight line between his departure and destination point and follow the indicated bearing, allowing for drift, winds and compass deformations. These are often referred to as dead reckoning procedures. The deformation resulting from the Mercator projection enlarges areas at an increasing rate with higher latitudes without angular distortion.

Over long distances, travel time is shortened considerably by flying great circles. From navigation by plotted dead reckoning, using Mercator projections, the requirements changed to easy direct measurement of true distances which was facilitated by projections with rectilinear great circle lines, such as the Lambert conformal conical projection. Additional influences in establishing this requirement were increased aircraft speeds, networks of radio aids, control of air traffic, and electronic distance measuring equipment which indicated an aircraft's position by its bearing and distance from its beacon. Radio navigation and plotting aids for use with GEE, DME, Vortac, Rebecca, and TACAN systems, and small scale aeronautical charts (1:500,000 and 1:1,000,000) therefore use the Lambert conformal conical projection with two standard parallels. On this projection, scale changes little within a single chart, and the projection provides particularly good directional and shape relationships in intermediate latitudes. With the projection great circle lines are straight, rhumb lines are curved and special aids are required to measure courses and bearing (Fig.1). Maps related to continuously generated material, such as the outside visual world, radar, or infra red line scan displays, require the minimum distortion along the track of the aircraft which may often suggest the need for an adapted Mercator projection. Large scale topographical maps (1:250,000, 1:50,000) for visual navigation and dead reckoning continue to use the Mercator projection.

The universal transverse Mercator projection is used on maps for polar navigation to provide a conformal projection base with least deformation along the meridian of 0° to 180°. In the tropics the original Mercator projection is preferred because this gives least deformation in tropical latitudes. A further advantage of Mercator projections in general is that a perfectly rectangular co-ordinate reference grid, known as UTM, can be superimposed. Projections for aeronautical charts have been discussed by Anderson[118]. Special photographic techniques are used to rectify maps when copying onto microfilm for projected map displays (Honick[119]).

The universal transverse Mercator projection is in widespread use for NATO military maps, including aeronautical charts. Tables are available to transform geographical co-ordinates into grid co-ordinates and vice versa, including those published by the US Army Map Service and by the UK Directorate of Military Survey. Maling[116] gives more technical details of the nature of these conversions.

Whereas for most of the above projections, the distortions within any single sheet are small enough in visual navigation not to have any major operational consequences, the rectification of doppler hyperbole on roller maps, and more recently the rectification of VOR and DME radials on charts for aerial navigation purposes may reduce the correlation with the ground to an operationally significant extent. There is little evidence on how much distortion can be tolerated without incurring operational penalties.

One problem however in worldwide mapping remains the derivation of information in a uniform projection from information originally gathered from many different projections. The kinds of task in long distance navigation which can be performed simply and those which require some special job aid or complex calculations may therefore lead to errors and depend considerably on map projection and in particular on what is held constant and what is allowed to vary.

The choice of projection affects the corrections which are permissible within each map sheet. In large scale maps, any changes are very small and even with small scale maps they do not constitute a large source of error compared with other sources of error present. They do not constitute equal sources of error in each dimension, but it is impossible for example if the scale is correct on all parallels for it to be correct on more than two meridians, and vice versa. The reasons for this are explained by Kellaway[115] and by Maling[116].

Discrepancies between different surveys make it difficult to position different areas in relation to each other without supporting photocrometric or satellite data. The accuracy with which cartographic information is depicted must be appropriate for the data sources. Spuriously accurate information is misleading and potentially dangerous. The difficulties in compiling a map from sources with different projections should however not be exaggerated, since each item of information does not have to be recalculated, and the relationships and rules to be followed can be derived from comparisons of the great co-ordinate systems. The changes are a matter of uniform or progressive distortions with graticule and grid with no sudden or unpredictable transformations.

2c COMPILATION

In compilation, source material is selected from available information for inclusion on the map. This may be done from geodetic data, from photogrammetry, from satellite information, from intelligence reports, from the knowledge of area specialists, or from existing maps, preferably from those of twice the production scale. To a large extent, the success of a map in meeting the user's requirements depends on how well informed the compiler is about what these requirements are, and on the appropriateness of his selection criteria. Many criticisms of aviation maps ultimately derive from the cartographer's ignorance of how aviation maps are used, and from the users' ignorance of how aviation maps are produced. As a result, criticisms made by each may seem ill informed to the other and are not treated seriously.

Compilation processes often require the transferrence of data using visual judgement. Graticules and grids are used as guidelines, and interpolations made by eye. The compiler must continually generalise and simplify, and in the absence of clear statements on map usage he may be forced to work intuitively. For a world-wide series, such as the 1:1,000,000 ONC, 1:500,000 PPC, and 1:250,000 JOG, more than one national production agency may be involved. Precise and detailed specification is necessary so that the content and appearance of the map do not depend on where it happened to be produced. As a result world-wide map series tend to be aesthetically dull, since any departures from the specification on artistic grounds must be strictly limited.

A basic map, or base map, is constructed from an original survey, usually with a specific fairly large scale in mind, so that the surveyed information is gathered with an accuracy appropriate for the final production scale. Most medium or small scale maps are derived from large scale maps and incorporate information from other sources which supersede the original in accuracy, in detail, in recency or in comprehensiveness. Some of the processes in compilation are described by Robinson and Sale[95] in general terms and Keates[120] provides a thorough appraisal linked to production technology. Keates also describes the application of automation to map compilation, particularly in relation to digital computers, and using the capacity for automated storage and information processing to circumvent the delays inherent in manual methods and the vagaries of individual's choice and interpretation of information.

As long ago as 1921, the importance of selecting the information content of aviation maps to match the special conditions of flying was recognised by Lees: "The design of air maps must be a logical one, controlled by the values

which the aviator places on the various objects seen from his machine". However, few cartographers are well acquainted with the particular conditions of map usage, for example in high speed low level flight. Representatives of the users are closely involved and largely determine the content of map specifications. Nevertheless these specifications still require some degree of interpretation by the cartographer when making detailed decisions in compilation, for instance about which water courses to portray in a particular area, without interfering with the portrayal of other vital information. Typically, the compilation instructions in a specification are in the form of guidelines rather than detailed instructions. The following examples are taken from the third edition of The Production Specifications for the Joint Operations Graphic Series 1501 and 1501-Air, issued by The Defence Mapping Agency in 1972. "When the term landmark is used within these specifications (i.e. JOG) it means that the feature selected as such is recognisable because of shape, size, location, or other unique or outstanding characteristics, whether the observer is on or above the surface of the earth".

"Power transmission lines shall be shown to a density short of over-congestion."

"The road net shall be well illustrated and all roads essential to the communications system must be included."

The sentiments expressed in these guidelines are undoubtedly correct, but in order to apply these concepts the compiler needs to be able to define the characteristics of features that make them "recognisable" or "essential to the communications system".

McGrath and Borden[121] distinguished five methods that have been used to develop selection criteria to aid the compilation of aviation maps, namely rational analyses, mathematical analyses, interviews and questionnaires, job or system anslyses and performance measurement.

Rational Analyses

In a series of papers issued by the Mapping and Charting Research Laboratories of Ohio State University Research Foundation, various proposals are made on map content based on rational analysis rather than on empirical studies. Following detailed analyses of categories of features useful for low altitude navigation, Summerson[122] concluded that maps should be individually tailored to each mission, and Miller[123] argued that the features portrayed should facilitate periodic checks on dead reckoning rather than continuous geographic orientation.

Angwin[63] argued against the validity of classifying features according to visual utility and supported the notion of mission specific charts. He suggested that a highly detailed planning chart should be produced, portraying every feature that might be useful for navigation. These features should be portrayed in a muted fashion so that the user, having plotted his route, could then manually emphasise the features he would use as checkpoints. Thus he proposed that the user should apply his own selection criteria for compilation. Although experimental versions of the muted maps were produced there is no record of them having been evaluated. Another feature of his proposed system was that a tape recorded commentary of the route should be played back in flight telling the pilot in advance what features he should look for. A disadvantage with armchair analysis approach to selection criteria is that although the arguments may be well founded it still tends to lead to general directives rather than specific practical recommendations.

Mathematical Analysis

Mathematical analysis has been applied to the selection of features for portrayal on maps as well as to the more traditional functions of defining scaling, projection and accuracy. Waters and Orlansky[24] developed nomographs from data on human vision to determine whether or not a feature of given size and contrast would be visible at given altitude. Meteorological range and the sky to ground brightness ratio were also taken into account in the prediction. A similar approach was taken by Miller[123] in considering selection criteria for low altitude navigation. In this formulae, visibility and time in view were a function of the size, contrast and shape of the feature and the meteorological conditions. This approach has the disadvantage that information is required which is not normally available to the cartographer, such as contrast ratio. If these unknown factors are assumed, the predictions tend to give more information than can be portrayed on the map. The cartographer is still faced with the problem of defining what the pilot can identify from the features he can see, without confusions, without confusing similar features. At low altitude, most features on the ground are visible; here the problem is one of distinctness rather than visibility. Finally there is the critisism that many of the assumptions made in the prediction of target detection performance are derived from laboratory studies using simplified visual fields. Predictions which are so derived may be unreliable when applied to the operational environment (Heap[124]). Other factors such as the pilot's visual search techniques and the complexity of the visual field affect target recognition performance (Erickson[125]).

Interviews and Questionnaires

Interviews and questionnaires provide a direct, economical and highly versatile means of obtaining information on map user's requirements, and they have been used extensively in research studies (Bishop, Waters and Orlansky[22]; Bishop Dorney and Channell[126]; Dornbach[127]; McGrath and Borden[65]; Murray, Waters and Orlansky[128]; Barnard et al.[129]), and by the production agencies (Bloom[130]). Questionnaires and interviews can be either unstructured and open ended or highly structured, or a mixture of the two. The degree of specificity of the question determines whether general guidelines or detailed analyses will be obtained. Rating scales and checklists provide a means of quantifying subjective opinions

on map content. For instance, Murrell[131] studied the content of maps for high speed low level flight and used rating scales to measure the importance of classes of features starting from specific examples on an existing quarter million scale map. This is a more logical approach than deducing the specific from the general, as tends to be the case with questionnaires. The end result is simpler in that the cartographer still has to interpret the importance ratings in terms of the compilations of specific features in specific contexts. For instance, importance ratings do not tell the compiler which specific examples of a class of features to portray, or when the examples of a class of features becomes so numerous that the meaning of each specific one starts to be lost. For example the portrayal of every small village in a region of many small villages becoming self defeating for many operational roles.

Combinations of, and interactions between, features often prove critical in the practical task of compilation. For instance, minor roads may generally be of little significance, but a particular minor road that runs alongside a railway or crosses it by a bridge may be highly significant. There are serious practical limits on how many of these interactions can be taken into account by interview or questionnaire. Pilots understandably find it easier to respond to general questions rather than rating scales when the latter are not highly specific. Furthermore, the use of descriptive labels such as "small town" and "forest cover" have different meanings to different pilots depending on their geographical experience. Generally there is a need for caution in interpreting questionnaire and rating scale data and the quantitative nature of the latter should not imply validity and objectivity.

Job or System Analyses

Cartographic requirements can be obtained from analysis of the tasks being performed, the navigation aids available, the workload of the pilot and navigator, procedures they must follow and their working environment. Both Bishop et al.[126] and Barnard et al.[129] used job analyses to define information content requirements for maps in helicopter operations. The method is indicative of a broader approach than the previous categories, and may include some or all of these specific techniques as well as performance measurement. A job analysis provides the logical start for any understanding of the selection criteria that are likely to be required by the user.

Performance Measurement

Performance measurement is the objective study of the effects of maps variables on the ability to map read and perform tasks. Measurements can be made in laboratory experiments, flight simulations, and field studies. Performance measurements can indicate the success or failure of different selection criteria by varying map content systematically (McGrath et al.[132]) or by comparing maps produced to different specifications (Lichte[58]; Osterhoff and McGrath[133]). Systematic analyses in which single factors are varied are difficult to arrange because of the high cost of cartographic production associated with the need to look at all possible interactions. Nevertheless when individual cartographic factors can be controlled, performance measurement provides the most effective means of analysis.

Although these methods have been distinguished as separate techniques they may be used together and they often are in developing selection criteria. The study by McGrath and Borden[121] of selection criteria for maps for high speed low level navigation utilised several of these techniques in combination, to good advantage. Eighty one pilots viewed film of low altitude missions over different terrain and indicated the usefulness of features for determining or verifying positions, irrespective of whether they were likely to be portrayed on conventional maps. Parametric characteristics of the features were determined from the films (size, shape, height, contrast, terrain context, vegetation context, hue numerosity, continuity, and a number of associated features). The existing maps were examined to determine whether or not the features were portrayed. A quantitative index of the visual utility of each feature was derived from analysis of the film response data. An index of the cartographic utility of the same features was derived from judgements of probable visibility and utility made by fifty eight pilots looking at maps alone. A third index, the selection rate, was given by the percentage of features portrayed in a given class. The method provided a variety of analysis including comparisons between selection rates of specific categories of features and the visual utility of these categories in relation to different clases of terrain, (flat, rolling, mountainous). The methods claimed by the authors as having advantages of being empirical, quantitative, systematic, integrated, analytical, flexible, simple, and economical. Limitations are that it may be specific to the terrain studied, that parametric factors may be confounded, that the visual field was not truly equivalent to that available to the pilot in flight and that information with no real world counterpart cannot be studied, such as aeronautical information.

In a separate experiment a quarter million map was produced according to selected criteria derived from the film analysis, and the map was compared with other conventional maps on performance in simulated high speed low level navigation. The results on navigation performance from seventy six pilots favoured the experimental map, although subjective ratings were less favourable. While this experiment indicates that the selection criteria used on the experimental were at least as appropriate as the other maps tested, the value of the experiment was reduced by the confounding scale and coding factors. The conventional maps were at 1:500,000 and 1:1,000,000 scale; the experimental map was 1:250,000 scale. Colour coding on the conventional maps was restricted by a red light legibility requirement but no restriction was placed on the colour coding on the experimental map. Nevertheless it is critical that the original analytical study provided sufficiently detailed results to permit a highly circumscribed specification to be drawn up. For example, the specification for the experimental map includes the following "all bodies of water larger than 50,000 sq ft in area were selected".

20

"Water courses with bank to bank width in excess of 50 ft were selected for portrayal, smaller water courses were selected when there was evidence of high contrast with the surrounding terrain."

This compares with the following advice from the Joint Operations Graphic production specification, "no attempt should be made to show all (drainage) features; instead, a representative pattern of symbols should be added to cover the area augmented as appropriate by an explanatory note as 'numerous small ponds, hot spring, etc.' ".

"Isolated small lakes and pools too small to plot to scale should normally be omitted. In the event that they are of landmark value, small lakes and ponds should be shown."

The process of compilation may also use information derived from air photographs and in future will rely more on photographs taken both from conventional aircraft and from satellites. Two main kinds of air photograph can be used for deriving cartographic information, vertical and oblique photographs. The former are less successful, as vertical photographs have to be taken looking directly downwards and need to be within 2 or 3 degrees of the vertical. Oblique photographs, from which it is easier to derive height information, are classified as high if they include the horizon in the picture and as low if they are at greater angle to the horizontal. Techniques for deriving information from air photographs, and correcting for possible sources of error, are described by Dickinson[134], who discussed the role of air photographs as a supplement to topographical maps, as an additional source of information to be incorporated onto existing maps, and as a basis for compiling new maps.

The interpretation of aerial photographs is a highly skilled task. Photo interpretation as a source of information on battle areas, target recognition, troop movement, targets states after attack, that is the traditional role of air photographs in wartime, is not within the scope of this volume. Aerial photographs are relevant to map compilation, to other tasks associated with maps and to other materials used in conjunction with maps. They may also be valuable during various operational roles and for route planning, briefing and debriefing (St. Joseph[135]).

The study of aerial photographs raised the major topics of pattern detection, pattern interpretation, selection of visual information, and the juxtaposition and superimposition of cartographic and photographic material (Kause[136,137]). The principles involved are highly complex, and extensive experimentation has often failed to reveal general principles of pattern interpretation, perhaps because of the uniqueness of each pattern and the apparently arbitrary psychological nature of most postulated classifications of patterns. General principles are difficult to derive because it is impossible to manipulate selective parameters of the aerial photographs corresponding to the traditional psycho-physical attributes normally controlled in psychological experiments of perceptual organisation and structuring. Clearly an essential stage in the acquisition of skill in interpreting aerial photographs is to learn to discriminate those perceptual differences which have operational significance. This in turn entails additional evidence in the form of unambiguous collateral material being available during the learning process. Such material, however, is difficult to come by under operational conditions, where for instance it is impossible to verify the content of an aerial photograph by inspection of its contents on the ground at first hand. Interpretation may therefore depend on skill and experience and there is the possibility that uniform agreed methods of training may entrench characteristic misinterpretations as well as reinforce correct ones. Some empirical confirmation that the interpretations of aerial photographs continue to be both reliable and valid is therefore desirable and prudent, to prevent false sets and expectancies associated with uniform training methods leading to agreed interpretations which are unconfirmed and may be wrong.

There is often a need to interpret information on aerial photographs as specifically and as definitely as possible. This leads to a problem in many military environments, either because of the failure to acknowledge the human limitations in pattern perception or because of an assumption that there must be usable information present. On a photograph it may only be possible to say that something, as distinct from nothing, is there although the operational demands are to state what it is. It may only be possible to assign a tentative classification whereas the requirement is for a position identification. It may be possible only to specify the class of an object, when details of its size, shape and orientation are required. The temptation is to try and be helpful by interpreting beyond what the psycho-physical content of the stimulus will bear. These are general psychological problems which have recurred in pattern perception which emphasise the need for caution in interpreting aerial photographs and they acknowledge the human limitations of pattern vision (Hake[79]), having sounded a warning, it is necessary to point out that many modern aids increase the confidence with which information may be derived from aerial photography. In particular the perception of relief can be very much enhanced and the quality of relief information greatly improved by the use of stereoscopic principles. Oblique photographs can provide good relief information at some cost in relating adjacent photographs coherently. Aerial photographs can be assembled into mosaics covering a much larger area. Normally only the central part of each photograph is used for this purpose to minimise distortions of scale and relative position. The main sources of distortion are described by Robinson and Sale[95] in their discussion of compilation from air photographs. Aerial photographs can potentially provide a means of updating information far more frequently than can be obtained by conventional maps, and for certain military maps uses this is of great importance. The ability to use colour in photography is also of significance although at present perhaps more for certain thematic mapping than as a basis for aviation maps. (AGARD Conference Proceedings No.90 – 1971.)

Keates[120], in discussed compilation, sounds a note of caution about the evaluation of disparate sorts of materials. It may be correct to ascribe data accuracy to material which conveys a clear and pleasing visual impression but it need not be so. It is necessary to guard against material which can convey spurious accuracy which may be misleading and

against material in which deficiencies in its presentation lead to underestimates of its quality. Keates also advocates the need in compilation to seek expert advice, particularly in relation to specialised mapping and in evaluating available published data sources.

2d DRAWING AND PRINTING

When all the information sources for a map have been collated, and the design specification prescribed, the conversion of this information into the basic visual content of the map by drawing can take place. This is a skilled task, requring training and practice until the requisite levels of expertise and dexterity have been attained. Although the cartographic draughtsman still has a major and skilled role in cartography, certain aspects of his craft are being modified or superseded by technical developments and by the introduction of automated processes, which inevitably tend to limit opportunities for flexibility, innovation and aesthetic judgement. Developments in printing, and changes both in the instruments and materials used by the cartographic draughtsman, require adaptations of his skills. Automated methods, if they are to replicate some of the most effective drawing techniques, require the quantified description of those techniques in a single precise way which can be set down as part of a computer program.

To some, the cartographer is identified with the cartographic draughtsman, whose main work is the drawing of maps. However, the two disciplines are not the same. While the cartographer needs some knowledge of cartographic draughtsmanship since what can be presented on maps must always be within the draughting techniques available, the same could be argued about his knowledge of photography, printing, inks and paper. Although skill in draughtsmanship may well be an asset for a cartographer, it is not a prerequisite, and Robinson and Sale[95] argue that a cartographer should not abandon his profession if he lacks this skill.

Most introductory texts on cartography make some reference to the drawing techniques and instruments commonly used. Robinson and Sale[95] devote a chapter to map construction, and Monkhouse and Wilkinson[139] give a full description of the accepted materials and techniques. These are so diverse that they cannot be fully described here. The subsequent phases of printing and reproduction are also described in most texts, and Dickinson[134] provides an elementary exposition of the main printing methods.

A much fuller treatment of the whole subject is that of Keates[120], who distinguishes three aspects of cartography, metrical, graphical and technical, although it is emphasised that cartography is a single discipline, already subject to excessive fragmentation and detrimental subdivision. The measurements and calculation involved in surveying and in other stages of deriving a coherent representation of a region, are the metrical stages. They have been mentioned above, and are not covered by Keates because of the thorough and adequate treatment elsewhere. The graphical stage is concerned with conveying information to the user and therefore treats the map as a graphic image, with map symbols constituting a language. This aspect will be covered in later chapters of this volume, but it is pertinent to note that this concept of a cartographic image has no exact equivalent in psychological theory, being visual as distinct from verbal, meaningful to some degree, normally two dimensional, existing as a real object, representational of spatial locations and interactions, and possessing aesthetic as well as functional implications.

The second part of Keates' volume, on the technology of map making, deals with the building and manipulation of cartographic images, while the third part covers the methods and organisation of modern map production. The book has the merit of being up-to-date in its description of modern map technology and automation, and amidst all the processes described from production planning through to map revision, the residual but key role of the cartographic draughtsman can be viewed in a truer perspective. Technological innovations in drawing and printing will make a progressively greater impact on the production of aviation maps in the future. The uniform standards which are desirable in coverage of the whole world or large regions of it, which are common requirements in aviation mapping, encourage the introduction of more precise techniques and of computer-derived methods, since there is a need for rigid adherence to standards, and a discouragement of artistic licence in order to achieve uniformity, no matter who the compiler or draughtsman may have been. These conditions of uniformity and standardisation on the whole favour the adoption of modern methods, which rely less on individual skill and craftsmanship and more on computer technology. A complete description of the organisation, materials and techniques used in map production is outside the scope of this book. However it may be helpful to outline briefly the main stages currently used in the drawing of topographical maps for air use. The production of most other air maps and charts tend to be simplifications of this process.

Guided by a production specification, which has previously been tested on experimental monographs, a compilation manuscript is drawn by normal pen and ink methods at the same scale as the final product, using source material available for the area of interest. In the major map production agencies the provision of source material is a specialist activity. Most military survey organisations have extensive libraries staffed by specialist cartographers whose function it is to gather, investigate, evaluate and revise source material. In some cases, the complete compilation may be produced by a specialist compiler or editor, eliminating the production cartographer from the compilation process entirely. Alternatively the production cartographer receives his source material complete with annotations and guidance as to the best information to be used for a particular part of the compilation.

In drawing the compilation manuscript, all the information to be included in the final product is assembled together graphically. The uniformity and completeness of the compilation can thus be checked and the selection, classification,

simplification, generalisation, plotting and arrangment of the graphic elements can take place, according to guidelines laid down in the design specification. Accuracy and content are the main considerations; the final product can be no more accurate and contain no more information than the compilation. The symbols used at this stage need only be an approximation of the characteristics laid down for the final product. Detailed coding constraints are normally imposed later. Thus the compilation is not necessarily delineated in colour and is often monochrome.

The manuscript usually consists of a base compilation drawn in ink on a plastic medium, with several transparent overlays. The base compilation provides the framework and contains most of the planimetric line work such as the projection and geographic co-ordinates, grid, drainage, cultural features, roads, populated places, and costal hydrography. Separate overlays are normally prepared for names, vegetation, and aeronautical information. Relief may also be separated when either the relief or planimetric information is dense.

In the next stage, sometimes called fair drawing, the information to be shown in each colour is separated from the manuscript by tracing. When many different kinds of information are to be shown in the same colour, such as names, railways, spot heights and grids in black, further component separations may be made to facilitate future revisions. The colour separations form the basis from which the production printing plates are made. Therefore, the design specification for the physical characteristics of individual symbols must be rigidly adhered to in fair drawing, unlike the compilation manuscript.

The line work in each separation may be traced as a positive image on a light table by pen and ink methods, or as a negative image by scribing. In scribing, an opaque surface coating is removed from a transparent polyester plastic material by cutting and peeling along the required lines, leaving the lines transparent against an opaque background. Special scribing instruments are used to cut away the coating. Tracing an image through the scribe coat is difficult and materials are available which photographic or diazo coatings which when exposed to the compilation, provide an image of the compilation that gives an accurate scribing guide. Scribing tends to be preferred to pen and ink methods because it gives a more precise, sharp and permanent image. The greater precision offered by scribing also facilitates standardisation, when large numbers of draughtmen are involved.

Pre-printed peel-coated stick-on materials may be used for patterns, screen tinting, type and stylised symbols. Tone images, such as hill shading, are produced by pencil or airbrush drawing. Apart from requiring a high contrast the colour of each separation is arbitrary in fair drawing; colour addition takes place in the printing process. All the materials used in making a map are normally uncoloured through the compilation and drawing stages, until the proofing (checking) and the final printing process. This contrasts with the usual artistic process, and means that aesthetic and artisitic considerations, if they are to be applied at all, may have to be introduced in relation to a single hue, without any direct visual evidence on their interacting visual effects in the final multi-colour map. The correlation between all the single hued images in the final product has therefore to be done derivatively and not by direct visual observation of the multicoloured final product. The ways in which these relationships can be deduced so that the correct juxtapositioning of the information in different colours on the map can be worked out depends on the processes by which the map is made. This may be a suitable role for a computer in future mapping, since the constraints are complex and cumbersome when expressed visually and drawn manually, but can be described relatively simply in programming terms. Recent advances in printing and reproduction have resolved many of the traditional intransigent problems, essentially by permitting greater flexibility in the intermediate stages of map production, including advances in proofing and in trial sheets. Great flexibility assists compilation by making it easier to transfer data, whether scribed or photographic, from one kind of surface or process to another. This has led to problems in the organisation of map production, which are now extensive enough for Keates[120] to devote a chapter to them. The automation of compilation and drawing processes and the role of computers have been described by Peucker[140], Keates[120] and Margerison. In digitising source material, the impact of computer technology on cartography will be considered later in this volume.

After compilation and fair drawing, four main operations can be distinguished:

(1) Photographing the fair drawings.
(2) Processing the negatives.
(3) Making the printing plate.
(4) Presswork.

Human factors are less important for the successful completion of these phases than in compilation and drawing, and they are therefore covered in less detail. The results of the photographic processes are a function not only of attributes of the camera, the film, and the conditions of exposure, but also of the illuminant and the processing emulsions. Photographic cross-line and half-tone screens, vignetted screens, and colours can pose problems of correction when the photographed image has to be printed. Photographic masks are used in conjunction with emulsions to control and vary contrasts. A variety of non-photographic processes are also employed in cartography, and Keates[120] describes ferric salts processes, dichromated colloids, diazo compounds, photochromism, photopolymerisation, infra-red and thermographic systems, and electrostatic processes.

Photographic processes are used to duplicate images during the preparatory stages of map production; they may also be used to produce multiple copies of the final product. However, multiple reproduction by photographic processes is time consuming and expensive. When large numbers of the final product are required, as in aviation mapping, multiple

reproduction is normally carried out by standard printing processes. In dealing with multiple reproduction by printing, Keates[120] distinguishes between intaglio, relief and planographic processes, and between platen, cylinder and rotary printing, noting that in practice the provision of large numbers of copies implies rotary printing, so that the printing surface must be in a form which can be applied to the surface of a rotary cylinder. The commonest planographic process is offset photolithography. In map printing the characteristics of the paper, particularly in relation to humidity and to contact with water and ink may limit choices in the design such as the number of colours, and the capacity of paper obviously influences the production and the final appearance of the map. Ink characteristics likewise influence appearance and production methods. Normally a map must be proofed before it is printed; the complexity of this operation depends on how many departments and points of view are concerned with the production of the map.

2e CONSTRAINTS IMPOSED BY PREPARATION AND PRODUCTION METHODS

Because the making of a map is an intricate process, complex and changing with technological advances, constraints on its visual appearance are intrinsic in map-making. To some extent therefore recommendations on prospective improvements in maps which depend on human factors knowledge may nevertheless be impractical. The human factors specialist must learn enough about the discipline to which his knowledge is being applied to avoid proposals or recommendations which merely reveal an inadequate understanding of the problems, and which call into question the value of what he says. However, it does not follow that the existence of an apparent practical constraint at the present time must imply that a potential human factors benefit should not be considered even if it appears to be impractical. One reason is that future technology may make it practical. Another is that constraints may be more apprent than real, the product of conventions or practice hallowed by tradition but not thereby rendered sacrosanct. Questioning them may either clarify the true reasons for them and allow a further judgement on whether these are compelling, or force discussion of attributes of maps which have been so taken for granted that the possibility of changing them, apart from the practicality or desirability, has never been seriously entertained.

The needs of the users or the requirements of tasks have not hitherto had a notable influence on the content or appearance of most maps; attempts to introduce such an influence are almost bound to engender some fundamental issues for debate when they are first made. One implication is that in the future a different kind of evidence may be needed to settle disputed aspects of the map image, based on empirical, impartial data which can be verified. The issue of the relative importance of a pleasing visual appearance of the map compared with its utility is likely to be raised: before it can be resolved, the criteria which are relevant in judging what constitutes a good map must be agreed. So far, there is nominal and even vehement agreement that the map must meet the needs of the user, and this is interpreted as meaning that it must provide in useable form all the information he needs to fulfil his envisaged tasks; but whether the needs of the user include a pleasant appearance of the map image, whether users can agree on what constitutes a pleasant appearance and whether the attitudes engendered by a pleasant or ugly appearance influence map utility are all debatable issues. Nor have cross-cultural differences, in thought processes, education, notions of geographic orientation and concepts of maps, been considered in designing maps with world-wide coverage. There is no reason to suppose that cross-cultural difference would be unimportant in depicting topographical information, in learning to use and understand it, and even in the allocation of subjective importance to different geographical features.

In considering the constraints imposed by preparation and production methods, it is possible to adapt the approach of introductory texts on cartography (Robinson and Sale[95]), to follow a historical perspective in relation to aviation cartography (Ristow[3]), to emphasise practical production methods in relation to various kinds of map (Monkhouse and Wilkinson[139]) or to describe modern production methods in a context which includes the logistics of map-making (Keates[120]). Whatever course is chosen, certain fundamental attributes of the finished product can be deduced from the methods which have to be followed. One of the simplest is that the map is essentially a human product at some stage. In the oft-quoted words of Wright[16], "maps are drawn by man and not turned out automatically by machine". As long as manual scribing, drawing, and positioning is entailed, there will be errors, not because of lack of skill or application, but because human beings are fallible and make errors. Furthermore, the nature and distribution of the errors can be to some extent predicted. Errors, which survive various checking stages, will be plausible, generally quite small, and difficult to detect. Although they may not be random in a statistical sense, they may nevertheless be subjectively random in the sense that their probability for any given reading cannot be determined by the user at the time. Because errors tend to be plausible, the user will have no means of knowing from any attribute of the map whether an error is present or not, until he has the opportunity to compare the map with the reality it represents. There will rarely be obvious discontinuities, discrepancies or logical fallacies, such as rivers flowing uphill. The accuracy of location of any given feature depicted on the map cannot therefore be deduced specifically from attributes of it. The accuracy of categories of map information can, however, be deduced. Errors on a particular category, taking a map sheet or series as a whole, will depend on map scale, map sources, the skills and tools of the draughtsman, the fidelity of the various processes in map production, and the specification. Usually, errors will be normally distributed, so that the accuracy of a category of information can in principle be stated by a mean error and standard deviation, or some other means of describing what is average and the maximum tolerable plausible error. This will not indicate for a specific example of that category at a designated geographical location the accuracy with which it is depicted or the size or direction of any error, but it will indicate how far that kind of information should be trusted, and to what purposes it may sensibly and justifiably be put.

It may be possible, knowing the quality of the original map information sources, in terms of professional or amateur ground survey, aerial surveys, traveller's tales, comprehensive or incomplete coverage, etc., to gauge what the quality and

accuracy of the depicted information is in general likely to be, but, with few exceptions, this is not differentially depicted on the map. Indeed there may often be no real justification for using a quantitative change in the map image to represent a qualitative judgement about information which is itself often qualitative.

It should however be borne in mind that expedients to increase the legibility of a map or reduce its clutter, by expanding photographically or otherwise, a small scale map to a large scale, multiply the magnitude of errors by the expansion factor, and may therefore produce a relatively uncluttered but also a relatively inaccurate map at the expanded scale.

One consequence of the advent of computer technology into map production, is that it may change somewhat the nature of the errors which occur. Some computer-generated errors may not be plausible and would therefore be detected quickly, and some plausible human errors would not be made by a computer. Errors which depend on the poor quality of the original data would of course remain.

Further changes in the nature of errors associated with automation are associated with the conversion of analogue to digital information. these are most easily demonstrated in relation to linear features, where the frequency with which a drawn line is sampled to obtain co-ordinates determines the accuracy of the digitised line in relation to the analogue original. Great accuracy can only be achieved by such frequent sampling that impractical quantities of points to be recorded, stored and collated would be generated, so that a practical compromise must be struck between the accuracy required for the envisaged user, and the expense of computer storage and collation. The necessary smoothing and rounding processes to prevent a smooth continuous line from being turned into a jagged one when digitised are described and illustrated by Keates[120], and the relationship between digital and analogue forms is examined more fully by Boyle[142]. Bickmore[143] has pointed out that both the typical output speed and the typical accuracy of plotting machines using digitised data are much lower than their maximum potential speed and accuracy.

The various sources of errors and inaccuracies during map production imply that the scale of the final map should somehow be influenced by the attainable level of accuracy, since the only way to imply accuracy without attempting to represent qualitative judgements about it in terms of differential quantitative coding is to use the factor of scale. It is intuitively clear that for example a 1:1,000,000 scale map will not depict the precise location of features on the ground as accurately as a 1:50,000 scale map, although the magnitude of this difference between scales is far from intuitively clear and would probably often be judged wrongly. However, it is misleading to employ a scale such as 1:50,000 for material which cannot bear this accuracy, since designated features must be placed at some precise position on the map, and such a scale encourages the belief that accuracy has been limited only by drawing skills whereas much larger errors may be present due to the quality of the data from which the map has been compiled. The problem of designating the quality of the information on the map, even when that quality is known, has not been satisfactorily solved by any method which enables the user to assign an appropriate level of confidence to the information being presented to him.

The sources of inaccuracy associated with map projections can be determined mathematically, and for most purposes their magnitude only becomes significant on small scale maps. Then it affects various map reading tasks differentially, depending in particular on whether the map can be treated as giving constant bearings. Normally the problem of providing sufficient accuracy for particular tasks can be solved by choosing a suitable projection and a suitable map scale, but any residual sources of inaccuracy from this source are specific to location on the map sheet and vary across a given sheet. The main practical implication is that this lack of uniformity of accuracy of a small scale map is not apparent to the user unless he has a detailed knowledge of the geometric implications of projection systems. The map sheet does in fact give some very indirect indication of error magnitudes, but only to a peculiarly erudite user. Microfilmed maps introduce their own errors associated with conical projection systems, and methods for overcoming these problems have to be found (Honick[144]).

Production processes are sources of inaccuracy only in so far as known difficulties in production have not been successfully allowed for or overcome. This applies to attributes of paper such as stretching, or of inks such as slight inconsistencies within a specification and variations in colour during the course of a print run. It also applies to various copying or photographic processes which form an integral part of the production method. Inconsistencies in lighting or photographic processing may introduce some variability, but the extent to which these can be tolerated before the casual, the informed, or the professional user can detect their presence has not yet been systematically studied by the traditional psychophysical approach to measurements. Perhaps for certain information categories much painstaking effort is expended to remove discrepancies in the image, the existence of which could not be detected in use by anyone.

Certain modern display developments have revealed interactions between methods of processing the map image and its visual appearance. The quality of the map image on a TV display depends on characteristics of the camera and the monitor. Projected map images derived from microfilm are affected by variations in photographic emulsions and photographic processing. These can lead to very large differences in the general visual appearance of such maps (Guttman[145]), and to some extent it is possible to vary the visual balance and relative prominence of various cartographic categories by the choice of film and by the use of filters during photographic processing. In practice, the main objective in choosing microfilm for projected map displays is to achieve a high contrast image which is resistant to fading during extended periods of use (Honick[146]). The psychophysical effects and their implications for perceptual structuring and for aesthetic appearance deserve more systematic study and cataloguing than they have hitherto received, so that their potential as a controllable source of variations in visual appearance may be known and put to practical use.

In general, the acceptance of technical innovations by cartographers should enhance the appearance and utility of their products, and give the user a more consistent and accurate representation of his environment (Heath[147]), although Harrison[148] suggests that art is as important as technology in map production. This acceptance may be of little practical value if it is not apparent from the appearance of the product that some improvement has been achieved, that accuracy has been enhanced, and that greater confidence may be placed in the information. Many of the constraints mentioned by Blaut[149] still apply with most automated methods and modern production technology, and indeed new constraints may be introduced (Peucker[140]).

Deficiencies in the portrayal of relief persist, although sometimes in new forms, because the vertical dimension cannot be represented directly on a two dimensional surface but has to be conveyed by various symbolic or pictorial conventions and strategems, leading to general visual impressions, and interpolations rather than exact measures. The precise distance between the designated points on a map can be measured exactly with a simple tool, though, as has been mentioned, this may convey a spurious accuracy depending on map scale, quality of data for map compilation, and sources of error in drawing and production processes. Comparable accuracy is not attainable in the vertical dimension except under the rare circumstances when both points coincide with spot heights or with contours derived from surveyed data rather than interpolated, there being usually no indication on the map whether they have been interpolated or not.

Blaut[149] also mentioned the almost unavoidable constraint that by visual juxtapositioning of information maps imply causal relationships or associations which may not exist. Some of these inherent constraints can be deduced from an analytic treatment of the elements of a map, such as that of Dahlberg[150]. A further constraint concerns the development of methods of evaluation and classification of map contents in terms which belie its nature. In considering maps drawn to a particular specification for a given purpose, it is important that any findings or evaluations apply to the whole map series, and are not region dependent (Taylor and Hopkin[151]). Yet the uniqueness of each geographical location and consequently of its cartographic portrayal is an essential feature of maps, to the extent that a map would tend to be accounted a failure by the users if it portrayed any two small regions in an identical way, the differences between them being important for discrimination but not for evaluation of the series.

It is possible to view the reliance of cartographic design on subjective impressions of worth rather than on experimental evidence itself as a constraint on map effectiveness. Additionally, in so far as maps have a language (Blaut[149]), which is translated by the cartographer through design principles (Dornbach[127]), this may be a source of constraints if inflexible standards and conventions for portraying map information perpetuate the notion that the usefulness of maps is dependent on learning their traditional language.

The constraints imposed by the traditional communication methods in cartography have repeatedly been questioned in relation to aviation use. One criticism has been the lack of co-ordination among those who collect data, coupled with long production delays in fulfilling recognised user needs (Bard et al.[152]). A rapid mapping capability may have to be developed (Schaubel[153]). If the need to reduce cross-referencing between the map and other information sources is postulated as important, then some common constraints may be abandoned (Freer[154]). Methods for incorporating photogrammetric data into map revision procedures have been discussed for a long time (Huffaker[155]), and effective procedures for map revision have been detailed (Keates[120]). Constraints may also originate in conflicting requirements of different mapping agencies (Bennet et al.[114]), as in the Joint Operations Graphic, a series which did attempt to show on the map something of the accuracy of its contents by marking unreliable features and by labelling approximations.

Problems of map revision and of keeping aviation maps up-to-date have been much discussed (ICAO Aero Chart Manual[156]) but the effort and time involved inevitably impose constraints. The use of maps as working tools, on which amendments are written by hand and information of a temporary or specialist nature is annotated, will probably always be a requirement under some circumstances, and this requirement may limit the functions of maps which cannot be annotated, such as those in projected map displays.

Accuracy is dependent on the choice and characteristics of tools for scribing. Gammon[113] suggests figures for the standard error in drawing (.01"–0.22") and in positioning during printing (.008"–0.5") and derives overall production errors. These of course will vary with the production technique, but with a typical error of 200 metres at 1:250,000 scale, certain effects can be deduced. The most obvious is the effect on positional accuracy but this may not be the most important. Since errors are not uniform in size or direction, the relative positions of adjacent geographic features may be misinterpreted, leading to changes in pattern perception and to consequent failures to recognise expected patterns.

Constraints may be considered in relation to cartographic information categories. The development of shading techniques in relief depiction introduces constraints in portrayal and interpretation (Harris[157]). Slopes have to be derived from other data, as distinct from being measured directly, and therefore are subject to inaccuracy when represented. Photogrammetry affords more direct evidence of slopes, and computers may facilitate the accurate derivation of slopes; but if the precision of the evidence exceeds the precision of the coding or the precision required for the users' tasks, then the effort expended in attaining that precision in the information about slopes has been wasted from the point of view of the user. Maps also place constraints on the number, positioning and lettering for place names on them. The principles for placing names on maps have been described by Imhof[158] who contended that there is a single optimum position on the map for each name. Design constraints also influence the depiction of woodland, the portrayal of which

must be compatible with relief. Often for aviation purposes, the information which can usefully be derived from depicted woodland may be less than the information which is lost by the superimposition of woodland symbols onto other information (Taylor[159]).

Technical advances may be the course of further constraints on map content and appearance, and the incorporation of earth-reference materials into maps for aviation purposes poses many problems (McGrath[68]). Also the constraints differ with the technological form of the map, and McGrath[160] describes problems of direct-view map displays, of projected map displays, of combined map/CRT displays, and of electronically generated map displays. New map forms were also surveyed by Wickland[161]. Making a plea for more use of three dimensional map images, Jenks and Brown[162] advocated using anamorphic transformations to reduce construction time for maps, and Adams[163] described a computer-drawn anaglyph map. Orthophotomaps may introduce further constraints and problems, and Hill[164] described how these might be tackled by comparisons between conventional and orthophotomaps. Smith's[165] findings suggested that the orthophotomap is less readable and he found that subjects took longer to find point symbols on it, but he warned that the factor of novelty could have influenced his results.

If any new technological cartographic development is taken seriously, as in the moving map display (Roscoe[166]), it brings its own cluster of constraints. Special cartographic support has to be provided (Boot[167]), including filmstrip support (Honick[168]; Defoe[169]), the production of special colour transparencies (Ferguson[170]), and their reproduction by contact printing (Honick[171]). In this regard, the new constraints associated with the moving map display are typical of those to be expected with any new major technological development affecting cartography.

CHAPTER 3

HUMAN CAPABILITIES AS CONSTRAINTS ON MAP EFFECTIVENESS

3a THE PRESENTATION OF COMPLEX VISUAL INFORMATION

In texts discussing the design of information displays, distinctions are usually drawn between broad types of simple and complex displays, and between human factors evidence relevant to each classification. Some authors make fundamental distinctions, such as between real and artificial displays (Singleton[110]), pictorial and symbolic displays (Morgan et al.[74]), and dynamic or static displays (McCormick[106]). Others consider in detail the kinds of information presented, and make distinctions such as between quantitative, qualitative, dichotomous, representational, concentric, integrated and graphic displays (Shackel and Whitfield[172]; Morgan et al.[74])

According to these classifications, maps are artificial, representational pictorial displays, combining a variety of pictorial and symbolic representations of both qualitative and quantitative information. McCormick[106] classifies maps as static displays because they remain fixed all the time, yet in moving map displays the information presented is subject to change through time. Therefore strictly speaking such maps are dynamic displays.

It seems that maps do not readily fit any simple classification of information displays. Most texts refer to a variety of different headings or to some general classification such as "complex configurations", along with other multi-dimensional displays of geometrical and spatial information (McCormick[106]). No single source gives a comprehensive integrated review of the relevant human factors constraints. The reader is forced to gather and compare information from a variety of unrelated sources. In this chapter an attempt is therefore made to review the principles of information display relevant to maps, arising from knowledge of man's sensory and cognitive capabilities.

If information appears in a form which cannot be seen or understood, much of the effort in providing it has been wasted. Broadly, information may not be used either because of inadequacies in its presentation so that the man cannot sense or resolve it, or because of inadequacies in its interpretation in which the information is sensed but not understood. Visual information as complex as that on topographical maps may have limited effectiveness either because of deficiencies of presentation, usually psychophysical in nature or because of deficiencies in interpretation, related to general limitations of perception, attention, decision-making, learning, or memory. The first two parts of this chapter distinguish between sensory and cognitive processes.

Knowledge of man's sensory capabilities allows estimates to be made of the probabilities that visual information will be detected or discriminated. From these probabilities it is possible to determine the limiting cases or thresholds for the visual system. For information sensed directly, threshold data can be used to predict detection rates, although this does not necessarily afford any means of changing visual performance. For information sensed indirectly and presented on displays, man can improve detection rates by controlling the presentation variables to ensure that the information is within sensory limitations. Because of man's involvement in display design, it is rare for indirectly sensed information to be presented at or below threshold levels on symbolic displays such as maps. A cartographic draughtsman is unlikely to draw something he cannot see. On the other hand, some forms of highly representational displays, such as radar and aerial photographs, allow limited manipulation of display variables, and threshold considerations become more relevant. Thus, limitations of man's sensory capabilities have usually been considered in relation to these latter forms of information display, and their relevance to maps has so far received comparatively little attention.

It can be argued that in recent years new forms of display media other than paper, new operating environments and new operational roles have extended the applications of maps in aviation beyond those originally intended by the designer. For instance the degradation of image quality in electronic and projected map displays and the effect of illumination, vibration and long viewing distances have led to threshold problems with conventional maps designed for hand held applications. Given that maps are not always used as the designer intended, knowledge of man's sensory capabilities may indicate which proposed applications may encounter sensory limitations and where a change either in map design or means of presentation may become necessary.

The Perception of Brightness

At the most simplistic level of analysis, the retinal projection of any visual information consists of a distribution of luminances. The response of the visual system to light intensity, the perception of brightness, is the first constraint on the presentation of cartographic information. A map must be illuminated, reflecting or emitting light above a certain

minimum level, before the map can be seen and stimuli on it can be detected. The absolute threshold for light intensity is that point below which no awareness of stimulation occurs. Absolute thresholds vary with the state of adaption of the eye, with retinal location of the light exposure and with the duration of the light. The minimum energy needed for awareness of stimulation under ideal conditions is about 100 photons, equivalent to a luminance of approximately 10^{-6} millilamberts (Hechtetal[173]). As conditions depart from this ideal, the absolute threshold becomes much higher.

Illumination at threshold levels is insufficient for map reading. The minimum brightness level for reading most maps is about 10^{-1} millilaberts. Approximately 10 millilamberts provides an adequate light level for map reading. The visual system is capable of responding normally up to about 10^{7} millilamberts (bright sunlight) beyond which exposure to light may become damaging. Map reading is possible at these high light intensities but visual discomfort can begin to occur above 10 millilamberts (Morgan et al.[74]).

Low brightness intensities of about 10^{-1} millilamberts may be used for map reading at night when the eye must remain sensitive to low levels of illumination. Following a change in illumination, it takes a measurable period of time for the eye to become maximally sensitive to the altered level of illumination. This period of adjustment is called adaption: dark adaption occurs when the new light level is darker, and light adaption when it is brighter. In map reading at night, if the source of map illumination is brighter than the prevailing ambient illumination, the eye will become light adapted, and some time will be needed for it to recover its full sensitivity to the ambient level once map reading has ceased. The recovery time is a function of the intensity, duration and retinal location of the light exposure. It may take as long as 30 minutes for the eye to recover full sensitivity, but generally if the map light is dim, the exposure brief and the area of visual field illuminated is small and viewed directly, the recovery time may be sufficiently short to have little operational significance (AGARD CP 26) (ref.[174]).

The time course of dark adaption can be shown by plotting the decrease in brightness (luminance) threshold as a function of time after exposing the eye to an intense light. The resulting curve has two parts, corresponding to separate dark adaption course of the rod and cone receptors of the visual system which are differentially sensitive to light. The cones are maximally sensitive at levels of illumination between 1 and 10^{7} millilamberts, known as the photopic range. The rods are maximally sensitive to levels of between 10^{-1} millilamberts down to the absolute threshold of 10^{-6} millilamberts, the scotopic range. Thus when the eye is exposed to an intense light, the rods take longer to recover their maximum sensitivity than the cones. At low light levels rod vision tends to be more important than cone vision and particular care must be taken to minimise the light adaption of the rods caused by periods of exposure to comparatively bright lights such as in map reading. The use of low level map illumination at night places constraints on map effectiveness. Most maps are less legible under low illumination. Special map design criteria need to be followed if similar map reading performance is to be achieved under both normal and low light levels of illumination. Because rods and cones are differentially sensitive to colour, red lighting is sometimes used to shorten the recovery time of the rods after exposure to light during map reading. Such a constraint has major penalties for map design.

Most map reading is carried out above absolute threshold levels and the main perceptual task is discrimination rather than detection. As the eye scans the map the visual system is required to respond to, or discriminate, changes or differences in intensity, called brightness contrasts. As with absolute thresholds, the differential threshold for light intensity – the just noticeable difference (JND) or the minimum change needed for a difference to be perceived – again varies with the adaption state of the eye, and with the retinal location, the area and the duration of the stimulation.

To determine differential luminance thresholds, the ratio of initial luminance L and increment in luminance ΔL is calculated ($\Delta L/L$). This is known as the Weber fraction. The ΔL that results in a just noticeable difference depends on the value of L. Generally, if the background luminance (L) is dim, only a small increase in luminance needs to be added to be seen as different. If the background is bright , the JND is larger.

The Weber fraction is not constant for the visual system. At very low levels of background luminance, say 10^{-3} millilamberts, a 1000% change is necessary for a JND. At normal map reading levels of illumination of about 10 millilamberts, a 10% change (1 millilambert) is noticeable. Hence percentage brightness changes that are readily perceived at normal levels of illumination for map reading (10ml) may be difficult to perceive at the lowest level used during night flying operations (10^{-1}) when the cockpit lighting intensity is reduced to preserve dark adaptation. For this reason, maps that are designed to be read at low levels of illumination tend to use unusually high contrasts between symbols and backgrounds.

At high levels of illumination the Weber fraction is approximately constant. Attempts to scale the perceived magnitude of luminosity give varying results, apparently depending on the scaling method used. Fechner[175] measured JNDs and found that brightness increased with the logarithm of luminosity. Stevens[176] used direct estimation of the magnitude of sensation by ratio scaling and his results showed sensory magnitudes to be exponential functions of the physical magnitude. The practical significance of these differences has been doubted (Wagenaar[177]).

The basic principles of scaling sensory magnitude have been used in cartography to design statistical symbols for representing quantitative data on thematic maps. Williams[178] concluded that Fechner's law was not applicable to grey (brightness) scales for maps since larger intervals than expected were required at the darker end of the scale. Numerous papers have been published on the scaling of greys and tones; some of these are reviewed by Crawford[179]. Ekman and

Junge[180] showed that map symbols intended to depict volume in fact were judged on their perceived area and were not efficient in creating the desired impression of change in volume. Other authors have used similar psychophysical procedures to construct scales with equal appearing intervals based on line widths (e.g. Wright[181]), circles (e.g. Flannery[182]) and squares (e.g. Crawford[183]). In general the guiding principle for the cartographer seems to be that logarithmic progressions in physical dimensions of map symbols are more reliably discriminated than linear progressions. Greater decoding accuracy is afforded by scales with logarithmic intervals rather than equal linear differences.

An important consequence of brightness perception for map reading is that the perceived brightness of a given symbol or area on a map is partly a function of the brightness of the surrounding area or background. Thus, a light green symbol for woods appears lighter in high terrain against a dark brown hypsometric layer tint than in low terrain against a light brown layer tint. This effect is sometimes called induced brightness contrast. One explanation of this phenomenon suggests that the effect is due to lateral inhibitory and excitatory processes at neural units connected to the receptors (Cornsweet[184]). Opacity of inks will also influence the brightness of overprinted areas. On maps, the complexity of effects of induced contrasts makes it virtually impossible to design scales of tone or brightness differences that have equal appearing intervals in all contexts.

The Perception of Colour

The perception of colour is largely dependent on variations in the wavelength of light. The eye is sensitive to light wavelengths between about 400 and 700 nanometers. Virtually all of the light that reaches the eye of the map reader is reflected from non radiating surfaces. The light reaching a surface may be composed of many different wavelengths and most surfaces reflect wavelengths differentially depending on the chemical or physical structure of the surface. Therefore the wavelength composition of light reaching the eye from the map depends in part on the composition of the illuminating light and in part on the nature of the map paper and on the spectral composition of the printing inks. These factors are the initial determinants of the perception of colour on maps.

The cones of the retina are primarily responsible for sensing differences in the wavelength of light. Both rods and cones are sensitive to wavelengths across the entire visible spectrum, but microspectophotometry has shown that whereas all rods give a similar response to light at a given wavelength, cones differ in response and can be distinguished into three types according to their spectral absorption function. This differential response is necessary for the perception of colour. For this reason colours tend to be seen best under normal daylight light levels when the cones are more sensitive. At low light levels when the cones are operating less effectively little colour can be sensed, therefore at extremely low levels of illumination maps appear to be achromatic.

Three separate cone spectral absorption functions peak at about 450, 530 and 570 nanometers, and are generally referred to as the blur, green and red receptors. Theorists have argued about the ways in which outputs from these receptors might be coded and transmitted. It can be shown that all colours can be made by mixing light in these three colours. This demonstration gave rise to the trichromatic or component process theory of colour vision, postulating independent links between each type of cone and the cortex (Helmholtz[185]), but neurophysiological evidence (e.g. De Valois et al.[186]) supports an opponent process theory of colour vision as suggested by Hering[187], involving interaction between the outputs from each sector. According to opponent process theory, red and green are coded as opposite, and so are yellow and blue.

The phenomenon of induced colour contrast can be explained by inhibitory processes consistent with opponent process theory. Hence, a grey square in a red background looks greenish but against a green background it looks red, against a yellow background blue, and against a blue background yellow. It seems likely that the background is producing some lateral inhibition into the grey area. Stimulating red cones in the background inhibits red cones in the grey area but not green cones thus inducing the complementary colour. Induced colour contrasts are frequently regarded as a serious problem in map design (Robinson[98]; Wood[188]) but attempts to measure their effects in a map context have been unsuccessful (Audley et al.[189]).

The perceptual experience of colour is complex. Three psychological parameters are normally distinguished in systems devised to measure and designate colours according to their appearance (Munsell[190]):

(1) Hue, corresponding to the dominant wavelength
(2) Saturation or chroma, relating to the purity of the spectral composition. A saturated colour consists of a single hue or narrow band of light wavelengths.
(3) Brightness or value, equivalent to the luminance or light/dark of colour.

These three psychological dimensions can be illustrated graphically as a colour solid or colour code (Fig.2). The circumference corresponds to the hue, the radius of saturation and the vertical dimension to brightness.

In the Munsell system, these three dimensions are scaled in units corresponding to equal perceptual intervals. One hundred equally spaced hues and up to 10 values and 18 saturation intervals are illustrated. The system has limitations; value and saturation are not psychologically independent, intervals on each scale are not perceptually equivalent, and the equal interval scaling of hue has been questioned, (Padgham and Saunders[191]). More precise specification of colours

can be made by CIE chromaticity co-ordinates based on mixtures of the three primary colours, red, blue and green. Nevertheless the Munsell system has many practical applications in cartography, such as deriving equal interval scales for coding quantitive map symbols.

Individuals differ in their perception of colour. About 6% of the healthy adult male population have marked reduced sensitivity to colour, and about 0.003% of all males are completely colour blind. Two general types of defective colour vision can be distinguished. The first consists of individuals who lack one, two or three of the types of cone receptors responsible for colour vision. Individuals having only two colour receptor systems are called dichromats; those missing two or three colour receptors are called monochromats. The second and larger group consists of people who are called anomalous trichromats: their colour vision may be anomalous because one of the cone types has a different spectral sensitivity function from normal. The commonest type of anomalous trichromat has an abnormal green function. Unlike poor visual acuity, colour deficiencies cannot be rectified by optical means. Tests of colour vision are available to identify individuals with defective colour vision, such as the Ishihara test and the Farnsworth-Munsell 100 Hue test.

With maps it may not be practical to ensure that all users have normal colour vision. Sets of surface colours have been developed that can be recognised by both colour sighted and colour blind individuals (Morgan et al.[74]) but the number of colours in such sets is less than that used on most topographical maps. Moreover some valuable conventional colour such as green may be omitted and magenta may be omitted entirely. If it is not possible to eliminate colour defectives from the user population, and if colour discrimination cannot be ensured, then the cartographer must use potentially confusable colours only as redundant codes, in combination for instance with shape or pattern coding.

Visual Acuity

If objects in the visual field are to be detected, they must have edges with luminance changes above the differential threshold of the eye. A visible object with adequate edge contrast may become so small as to be invisible when it is moved away from the eye. Thus size of an object and its distance, that is the angle it subtends at the eye, are important factors in visual detection.

The smallest visual angle the eye can discriminate is known as its visual acuity. There are several methods for measuring visual acuity and the results vary with the method used. The most sensitive index of visual acuity, the minimum acceptable acuity, measures the ability to detect the smallest possible target – a spot varying in diameter or a line varying in width. Generally, a line of about 1 half second of arc can be seen 50% of the time. (Haber and Hershenson[192]).

In map reading, map symbols are rarely very small and the ability to see small detail, shapes and patterns is a more important constraint. This ability is called gap resolution or minimum separable acuity, and it is measured by the smallest space the eye can detect between the parts of a target. Generally the finest resolution that can be achieved 50% of the time is about 30 seconds of arc. The practical limit for maps to be read under normal conditions is probably about 1 min. of arc. Individuals vary in their acuity, usually due to accommodation factors, and accommodation can be improved by prescribed visual corrections. Standard clinical eye charts measure acuity by comparing the standard distance (20 feet) needed to see the lines of a letter subtending one minute of arc with the distance that letters recognised by the observer have to be for the lines of the letters to subtend 1 min. of arc. Thus, 20/20 acuity corresponds to a resolution of 1 minute of arc, 20/10 acuity is better than the standard and is about the lower limit, 30 seconds of arc; 20/40 is worse than the standard and about 2 minutes of arc.

Visual acuity is not constant but varies with several factors, including the illumination of the target, its retinal location, target contrast, the adaption state of the eye, vibration and movement. Considering illumination, there is relatively little change in acuity in the rod or scotopic range of luminance, up to 10^{-1} millilamberts. Above this level, acuity dramatically increases as the cones begin to function. This occurs because the cones have more one-to-one connections with the neural cells supporting them, whereas the rods tend to converge on similar neural pathways. Thus signals from the cones tend to be spatially precise whereas signals from the rods tend to be spatially integrated. Retinal location is important because cones are denser in the fovea than in the periphery of the retina. Therefore visual acuity is greatest and the Weber fraction is at its most sensitive in the fovea. Fall off from the centre is rapid, and the eye has great difficulty in resolving the detail appearing in the peripheral rod-dominated areas of the retina although movement may be detected quite efficiently. Eye movements normally position the target at the fovea where it can be better resolved.

Acuity is reduced if the illumination is dim, if the contrast on the map is low, if the eyes are not adapted to the brightness level of the map and its immediate surround, or if the retinal projection is blurred either through vibration or through eye movement. All these factors are likely to vary together or independently during map reading in flight. Consequently maps which present information at near threshold levels under ideal viewing conditions are likely to prove inadequate in flight.

Whether or not a map symbol of a given size will be resolved by the eye depends on all the factors mentioned above, but because the angle it subtends rather than its size is critical, resolution will largely depend on the distance at which the map is reviewed. Most hand-held maps are designed to be read at distances not greater than about 500mms. Resolution difficulties in map reading, for instance because of poor illumination, can often be overcome by bringing the map closer

to the eye. On the other hand, resolution can be degraded if the map is presented at a distance greater than its designed viewing distance. This is likely to occur with automated map displays mounted on aircraft instrument panels, and special precautions may be needed such as magnification of the map image to recover the original angular subtense.

Visual Search

High acuity, sufficient to resolve shapes and patterns, is available only in the fovea of the retina, a region which extends over a visual angle of about 2°. Eye movements, supplemented by head and body movements, are necessary to utilise the high acuity of the fovea over the whole visual field.

The process of acquisition by eye movements is known as visual search. Variables that determine the effectiveness of visual search are important constraints on the presentation of visual information, particularly on maps where the arrangement of information remains largely unstructured, where the locations of features are difficult to predict, and where the information display often covers a large visual angle. For these reasons, search time is one of the most frequently used dependent variables in map research (Landis et al.[193]; Bartz[194]; Beller[195]).

Three types of eye movement can be distinguished – voluntary saccades, involuntary movements and pursuit eye movements. Saccadic eye movements occur when the point of fixation changes during scanning. Involuntary miniature saccades, rapid eye tremor and slow drifting movements occur during fixation without the observer being aware of it. Pursuit movements occur when tracking a moving target and they tend to be slow and smooth when compared with saccades. Map reading involves pursuit eye movements when either the map is moving or a position indicator is moving over the map as in most automatic map displays.

Vision is affected during eye movement. Sensitivity is reduced substantially during saccades and for about 50msec before and after these movements (Haber and Herchenson[192]). Yet we are not totally blind during saccades. Some detail can still be resolved, but the chances of new information being resolved are much reduced once the movement has been undertaken. Reductions in sensitivity associated with eye movements are usually attributed to visual suppression, the purpose of which is to minimise the perception of blur. Rapid pursuit eye movements may incur some loss in acuity at angular velocities greater than 20°/second, but the speeds of moving map displays (less than 3°/sec at 1:25,000 scale) are usually sufficiently slow for this not to be a factor (Carel et al.[196]).

Saccades of ballistic movements, their path and destination, are determined before the movement starts, and cannot be corrected once begun. Sudden movement or displacements of objects in the visual field are frequently the stimuli for saccadic movements. In map reading of hand held maps, the stimuli are stationary and the movement will be initiated following extra foveal peripheral processing of the stimulus attributes such as colour and size.

Eye movement patterns during map reading can be measured by a variety of techniques including electro-oculography corneal reflection and photography (Enoch and Fry[197]; Shaw[198]; Jenks[199]). Results typically show systematic rather than random movements associated with the structure of the visual fields and with the relevance of the features to the map reading task. Irrelevant features tend not to be fixated. During search, peripheral information is used to determine the next fixation, and search patterns only become random when the observer has information about the target he is searching for. Random search is only likely to occur in map reading during tasks such as area familiarisation and map study. In flight the observer usually knows what he is looking for and often, within equal limits, where to look.

Some cues are move useful in guiding search than others; orientation, size and colour are better than shape because the latter often requires a degree of resolution that is not available in the periphery of the retina (Williams[200; 201]). Studies on the attention getting value or conspicuity value of target parameters such as colour are extremely relevent to designing maps that can be searched effectively.

Fixation times and inter fixation distances are measures of search performances, and they can be used to assess map efficacy. Short fixation times and long inter-fixation distances are indicative of efficient visual search and display quality (Enoch and Fry[197]). Fixation duration indicates the time taken to process the stimulus, and may be expected to be longer for difficult map reading tasks and for poorly designed maps since these require more processing. Inter fixation distance indicates the effectiveness with which extra-foveal information is processed. Distances increase when the relevant target attributes are highly conspicuous in peripheral vision.

Fixation duration on average tend to vary between 250 and 350 ms (Barber and Legge[202]). Investigation of attention fields by Sanders[203] suggests that peripheral vision can process information up to about 30° into the periphery under favourable conditions. Saccades are therefore unlikely to be larger than 30° during structured visual search, and in practice tend to vary between 10° and 30°. Beyond 30°, eye movements are necessary, and beyond 80° the head must move. The areas corresponding with these angles are known as stationary fields, eye fields and head fields respectively. An important limit of eye movement recordings is that they do not necessarily indicate what the observer is attending to. Attention may be directed at peripheral stimuli, for instance in preparation for the next eye movement, or it may be directed to inputs received through other sensory channels such as hearing. The point of fixation can only be considered as the most probable locus of attention, at any given time. Individual differences may also possibly be important, even in for example in influencing fields which are searched (Johnston[204]).

The efficiency of eye movement patterns suggests, an optimum size for map displays. Enoch[205] recorded eye fixation during visual search of maps subtending visual angles at the eye between 8° and 51° 18 minutes. The results showed that, with maps subtending greater than 9° visual angle, fixations tended to concentrate around the centre of the map, and few occurred in the periphery. With smaller maps subtending less than 9°, fixations tended to be made outside of the map area. This suggests that map displays of subtended angle of about 9° or having a diameter of about 5 inches at 30 inch viewing distance, are near optimum in terms of efficiency of eye fixation patterns. Most map displays in aircraft cockpits are approximately of this size.

3b THE INTERPRETATION OF COMPLEX VISUAL INFORMATION

The foregoing section discussed sensory factors involved in the detection, discrimination and resolution of complex visual information. In this section, perceptual and cognitive factors involved in the recognition, identification and interpretation of complex visual information will be considered.

The interpretation of complex visual information has been the subject of prolific research for many years. As early as 1965 a survey of the literature produced 245 references in the area (Kause[137]). Some of this literature has been intended to improve knowledge and understanding by establishing facts and building theories. Some has considered the practical problems of interpreting complex information in numerous settings. Despite all this effort the current state of knowledge does not provide a great deal of practical guidance for resolving applied problems. For instance, McCormick[106], in his standard text on human engineering, refers to only eight studies in a five page discussion of complex information displays.

Related research on pattern recognition and form perception has demonstrated that numerous factors influence their interpretation (Hopkin[80]; Zusne[206]; Corcoran[207]). Hopkin[80] included the effects of such factors as visual content, verbal labelling, set and learning. Most of these factors which apply in interpreting simple forms are still present when complex material is interpreted and in addition further factors and interactions are also present.

Some notion of the complexity of the factors which may be treated as dimensions of visual information displays can be derived from the work of Siegel and Fischl[208, 209]. They concluded that the experience of the user partly determined what was the best display. Interactions between the user and the display were highly important with complex displays such as maps, but these interactions are not usually considered in display recommendations. Operators distinguished seven relevant dimensions of displays which the authors interpreted as stimulus numerocity, primary coding, contextual discrimination, structure scanning, critical relationships, cue integration and cognitive processing. Each of these seven is itself complex, and on maps interactions may be expected between them. Whether these dimensions are valid for all maps is debatable.

Many military tasks involve perception and interpretation of complex visual information. If general laws can be derived in the laboratory that remain valid in applied contexts, their potential value is very great in terms of saving of research effort and improved efficiency of tasks and systems performance. But the more factors which are discovered to be relevant, the more difficult it becomes to derive general laws which will encompass all of them and their interactions. Some twenty years ago major publications considered form discrimination (Wulfeck and Taylor[210]) and pattern perception (Hake[79]; Weisz et al.[211]) in relation to military visual problems; in some respects the progress made since that time has not been spectacular. Subsequent research has often tended to invalidate previous findings rather than to extend the body of established facts (AGARD CP-41[212]). The pictorial display of information for reconnaissance interpretation has long been considered a major problem (Whitcomb[213]; Sadacca et al.[214]; Sadacca and Schwartz[215]; Nelson et al.[216]). Maps are used as briefing aids and as collateral material for reconnaissance tasks. Consequently, a substantial proportion of the literature considering map reading as a complex visual task, derives from reconnaissance interpretation problems (Lichte et al.[56]; Bush et al.[217]; McKechnie[218]).

Attention

Limitations on man's ability to handle and process information are a major constraint on map design and map reading performance. Unlike a camera, man cannot look at a visual display, such as a map, and sense and record all the information both immediately and accurately. Perception is an active process and man must scan the display, and selectively take in and process the information in a serial rather than parallel fashion (Miller[219]). This process is called attention (Treisman[220]; Moray[221]). If a large amount of information is displayed for a short period of time, some of that information may not be attended to and therefore not processed. Thus, in map reading in flight, when the map must be read at a glance, a cluttered map containing large amounts of irrelevant information is likely to be a disadvantage (Taylor[222]). Ringel and Vicino[223] were concerned with map-like stimuli among others in determining how information assimilation was affected by the amount of change introduced when information was updated. The type of errors made, rather than accuracy, tended to be affected by such changes. They concluded that it was operationally advisable to confine the information on a single display to the essentials. Other authors have studied the deleterious effects of increasing information density on map symbol legibility (Hanby and Shaw[244]). Generally, there has been very little research on the effects of information density and generalisation on map reading performance, and there are few practical guidelines for the cartographer concerned with the selection and compilation of map content.

In order to increase the rate of processing of complex visual information, man tends to perceive stimulus elements in groups or clusters. The groupings that are formed tend to be those that past experience has shown to be highly probable and highly relevant. This process is known as perceptual organisation or perceptual structuring. In map reading, it allows the trained and experienced map user to integrate related codings and perceive relationships such as between contours, hill shading and layer tints (Jenks[199]). On the other hand the map may be difficult to work with if the user is inexperienced, or if the coding is poorly designed and difficult to integrate. Illusory perceptions are possible, such as the inversion of perspective with hill hading. Exaggeration of coding dimensions may facilitate perception, as in feature generalisation and in three-dimensional mapping (Jenks and Caspall[225]).

Generally, man prefers to work with information displays that are structured and organised (Landis et al.[193]) and that require minimum attention (Massa and Keston[226]). In map design, the cartographer can facilitate processing by imposing organisation, structure and integration through coding methods. Many general design principles are recognised in the cartographic literature. Some of these include the selective emphasis of features according to task relevance, the separation of information into visual planes, visual balance and symmetry, association by grouping, proximity,continuity, closeness and placement, figural goodness and figure-ground segregation (Wood[188]; [227]; Dent[228]; Keates[120]). These concepts draw largely on the principles of Gestalt psychology (Hochberg[229]) and the graphic arts (Arnheim[230]). To some extent, they have been more systematically applied in the design of symbols for machine displays (Easterby[231]).

Constraints on the interpretation of complex visual information arising from attentional factors are incorporated in most contemporary theory on human pattern recognition (Neisser[232], and Haber and Hershenson[192]). During visual search the eye fixates on distinctive features with high information content and the sensory image is built up and integrated from a series of visual snap-shots (Mackworth and Morandi[233]; Hochberg[234]). This process is sometimes called figural synthesis. Similarly, when patterns and shapes are remembered and recognised it is usually on the basis of their distinctive features rather than their detailed form. Perception, it is argued, is therefore a process of individual feature analysis rather than a process of template matching. The perception of form or pattern is an integration of the individual elements at a later stage of processing. Given this, it follows that symbols are more easily recognised and identified if their important distinguishing features are emphasised in design, and made highly discriminable. Partially relevant and irrelevant features should be visually suppressed or omitted altogether. To a great extent, this principle is followed in the generalisation of linear and area features on maps at progressively smaller scales. Often it is neglected in the design of alphanumeric, geometric and shape symbol codes.

Memory

Map symbols are recognised and identified by associating the physical characteristics of the stimulus with meanings stored in memory. Two kinds of human memory are normally distinguished; short term and long term memory (Atkinson and Shiffrin[235]; Norman[236]).

(1) Short Term Memory (STM) is a temporary, limited-stay, buffer store in which information received through the senses is held prior to central processing and incorporation in a permanent storage. Short term memory has limited capacity; information is rapidly lost (forgetting) by trace decay or interface from other incoming items, unless rehearsal occurs. In recall from STM confusion tends to be due to physical characteristics (acoustic or visual) of the stored stimulus rather than its semantic correlates. This latter research finding suggests that information stored in STM is encoded on a sensory rather than semantic basis.

(2) Long Term Memory (LTM) is a permanent store with unlimited capacity in which information is mostly coded in a semantic representation containing a meaningful structure. Visual information may be encoded visually or verbally but, generally, the more meaningful and organised information is easier to memorise and recall. Errors in recall from LTM are usually characterised by semantic rather sensory based confusions. Inability to recover information held in LTM, or forgetting, is most likely due to a failure in the recall process rather than permanent loss of memory trace decay. Unlike tape recorders, there is no erasure facility in human LTM; once items have been entered in the LTM store then they may always be recalled.

During map reading, both the STM and LTM have important roles, depending on the precise nature of the task. Tasks requiring the immediate identification of symbols without reference to map legends, rely largely on information stored in LTM. Tasks requiring the matching or visual correlation of maps with other complex visual or verbal information, depend on STM as well as LTM factors. Here the main constraint on map effectiveness is the limitations on the amount and duration of information that can be held in STM without being transferred to LTM (Sekuler and Abrams[237]; Cohen[238]). Pre-flight planning and route study involve committing map information to LTM rather to STM, and here the major constraint on map effectiveness is the ability to store the information and recall it when required.

In map design, the cartographer can minimise the users difficulty in storing and recalling map information from memory by displaying the information in a structured, organised manner which can be readily encoded in memory, and by using symbols that are immediately meaningful and have high association value. An early study by Koponen and his colleagues[29] in relation to aeronautical chart symbols demonstrated the finding, since repeated in many other contexts, that the associational value of symbols is pertinent and that it is determined by several factors. He concluded that effective chart symbols should quickly bring to mind the objects they represent and that, given a choice, subjects most frequently select symbols pictorially similar to the feature they represent. He recommended that symbols should have a

common meaning that could be interpreted by most people and noted that many of the existing symbols had low associational value. Research on the relative merits of different colour, shape, geometric and alphanumeric codes is highly relevant to this problem (Hitt[239]; Smith and Thomas[240]; Smith et al.[241]). On the other hand, the map user can improve his map reading performance by memorising the meaning of the map symbols rather than relying on occasional glances at the map legend, and by developing techniques for memorising patterns of map information that facilitate recall and increase meaningfulness.

One constraint on map design imposed by LTM is that once conventions become established and symbols become associated with specific meanings, any subsequent variation in symbol usage is likely to cause problems for the user. For some users, for instance, a given colour will tend to produce a given response, and only extensive learning and re-familiarisation will overcome this problem. New map designs are invariably at a serious disadvantage compared with existing maps because of the difficulty of learning new meanings for old symbols and vice versa.

Perceptual Learning

The process whereby information is stored in long term memory is known as learning. Many military map reading skills and techniques are taught, learnt or acquired from experience (Anderson[242]; Pickles[243]; Drury[244]). One of the least understood skills is that which allows an experienced map user to look at a map and apparently obtain far more useful information than the inexperienced observer. Such perceptual learning draws upon a variety of complex perceptual factors which psychologists have barely begun to understand.

The little understanding of perceptual learning that has been gained derives mainly from indirectly related studies of radar displays, such as those reviewed by Lichte et al.[56]. Some studies have demonstrated the importance of active participation in memorisation of complex visual information (Mayer[245]), and the effects of positive transfer from previous form discrimination learning to subsequent tasks (Hake and Eriksen[246]). Others have compared student's and instructor's performance on reconnaissance interpretation tasks (Lichte[247]), and demonstrated the importance of feedback on perceptual learning (Lichte et al.[56]). Numerous studies on teaching perceptual map reading skills have been carried out with children (e.g. Carswell[248]), whereas military studies have mainly been concerned with identifying the individual map skills, not specifically perceptual, involved in land navigation (Findlay et al.[249]; Cogan et al.[250]).

Expectancy and Perceptual Set

This interpretation of complex visual patterns, and all other sensory information, is partly influenced by information received by the senses and partly by information stored in memory. Stored information tends to be utilised mostly when events are highly probable and predictable, thus reducing the amount of sensory information that needs to be processed. But it is abused when workload is high, and when information received by the senses exceeds the organism's channel capacity, when the sensory information is inadequate, degraded or incomplete, and when the organism is stressed. The influence of stored information on perception is known as expectancy, or set. In the case where a highly probable event is perceived, the perceiver is said to have an expectancy or is 'set' to perceive the event. In the interpretation of complex visual patterns, such as maps and collateral information, expectancy may be beneficial to the extent that it increases the rate at which the information can be processed. Knowing the nature of the sought feature improves search performance for instance. Experienced map readers probably have good perceptual sets. Expectancy can also be a disadvantage when it leads to a false hypothesis about the nature and meaning of the stimulus pattern. Thus, expectancy may lead to an erroneous interpretation of terrain shape when an unfamiliar configuration occurs or when unconventional map coding is used, such as layer tints indicating 'the-lighter-the-higher' rather than 'the-darker-the-higher'.

Individual Differences

In addition to those constraints which are common to all (insofar as they are inextricably associated with the visual mechanisms for processing information) there are individual attributes, relatively stable, innate and uninfluenced by learning, which systematically affect the meanings and interpretations assigned to complex visual stimuli by the individual. One of these is the nature of the individual's imagery which is most commonly visually dominant but is not always so. The ability to recall past visual stimuli and situations, and the clarity and level of detail which is associated with such recalled images, vary greatly among individuals. In extreme forms, these differences can have marked effects on learning methods and efficiency, as for example, in those with a photographic memory. The topic of imagery, and individual differences in it, fell into disfavour in psychology, partly with the advent of learning theories and a behaviourist approach and partly because it did not lend itself well to many of the traditional experimental methods. However, recently renewed interest in the subject of imagery has arisen and there are several textbooks (Biderman[251]) and collections of papers (Sheehan[252]) considering further aspects of imagery. Further papers have extended the concept to mental maps, and to theories of pictorial representation (Gombrich[253]). While it is agreed that the principles of design should be known to the map compiler (Balasubramanyan[254]), this should be done in relation to knowledge on mental imagery. Similarly the consideration of illusory effects associated with certain cartographic conventions (Clarke[255]) might also be related to visual imagery. Attempts to apply the principles of visual perception to map design show a greater appreciation of the visual structuring principles than they do of attributes of the map user such as imagery which may nevertheless substantially affect map usage and design (Wood[188]). Jenks[199] noted that more map information could be stored in the memory than could be reported verbally and since each map user had a memory of a distribution the question of whether all these users had similar or different memories and images and whether the image of the user matched the image of the

cartographer becomes important. Jenks considered this problem in relation to geometric mapping, but it has wider applications. He also reported gross individual differences in the eye movements of people while map reading. Williams and his colleagues[256], in considering eye movement recordings, suggested that in order to predict search time adequately for maps, effects of the central and peripheral discriminability of information would have to be quantified. Images however are highly relevant here if only because of the reported findings of Sheehan[252] that the scanning of images does not necessarily involve eye movements and therefore need not be represented on eye movement recordings.

Tests of individual differences in intelligence, spatial ability and related personality measures such as field dependence/independence (Witkin[257]; Thornton et al.[258]) might be expected to be related to map reading ability in adults (Lichte et al.[56]). There is considerable evidence relating individual differences to map reading ability in children and adolescents (Rushdoony[259]; Fischer[260]; Carswell[261]; Killman[262]; Plumleigh[263]; Riffel[264]; Murdock[265]). Research on individual differences in adults is comparatively limited. Tallarico et al.[266] found that Army basic trainees with high intelligence were more skilful on map reading tests prior to training, and learnt more during training than lower intelligence groups. Findley et al.[249] found significant intercorrelations between tests of general reasoning (reading, vocabulary, arithmetic reasoning) spatial abilities (pattern analysis, spatial orientation, spatial visualisation) and a variety of map reading and land navigation tests in 96 Army personnel who had recently completed combat training. Phillips et al.[267], in a study of the legibility of relief maps, obtained a fairly high correlation between a test of spatial imagery and a general score of map reading ability but it did not give good predictions of subjects' ability to visualise relief.

3c GEOGRAPHICAL ORIENTATION

Geographical orientation is treated separately from other sensory and perceptual constraints on map effectiveness because of its particularly high relevance to map reading in flight. The concept of geographical orientation refers to an ability to sense or know one's location in a geographical setting, by designating it either in absolute terms such as co-ordinates or positions on a map, or in relative terms such as its orientation with respect to other features. It includes notions of direction, however these were expressed, and geographical disorientation is normally equated with being lost or uncertain of one's whereabouts. It need not rely on vestibular mechanisms, posture, balance or the force of gravity, which concern spatial orientation (Howard and Templeton[91]). However, a loss of spatial orientation may precipitate geographical disorientation, and vice versa. Nor does it necessarily imply movement through the environment, although a study of such movement may suggest potential causes of disorientation (Reason[268]), and may be helpful in specifying the perceptual cues, such as velocity gradients (Gibson[78]), which may be utilised during flight.

The problem of geographical orientation received surprisingly little attention during the Second World War and for some time afterwards, although there was substantial anecdotal evidence that aircrew often got lost, (e.g. Vinacke[269]). Clarke and Malone[270] regarded it as a truism that aviators may become geographically disorientated. More recently, McGrath and Borden[65] surveyed accidents and incidents involving geographical disorientation and noted that it was taken for granted that pilots became lost from time to time, particularly on low altitude missions. Consequently, they tended to ask pilots for details of a recent or serious instance of geographical disorientation, rather than ask whether they had ever experienced such incidents. These authors surveyed accounts of disorientation with a view to classifying causes and generating hypotheses amenable to testing by scientific methods. Their findings indicated that maintaining geographical orientation in flight was a mjaor problem, the seriousness of which had at that time not been realistically acknowledged.

Despite its great operational significance, geographical orientation has not been viewed as a prime topic for human factors research, and not much of the research done on geographical orientation has had an aviation context or application. Studies on children, on primitive peoples, and on the blind provided the main sources of evidence on the ability to maintain orientation within a geographical environment, and in some respects they still do.

The strength and persistence of incorrect orientations, the associated emotions of unease and stress, and the contributions of distractions, forgetting, and inadequate cues to disorientation were all noted long ago (Binet[271]). The apparent lack of any innate sense of direction in children, is also a longstanding finding (Smith[272]). With increasing age, children can make more effective use of maps, but cannot make effective use of the main compass points (Lord[273]). Aerial photographs can improve spatial understanding in children (Hart[274]).

A large variety of sensory cues, some quite tenuous, may be enlisted in maintaining geographical orientation, especially among primitive peoples in featureless but familiar environments (Lynch[275]; Lewis[84]). Their use may convey a false impression of a special sense of geographical orientation. Such cues may be employed to maintain a cognitive map for navigation (Oatley[276]). Galler et al.[277] have collated current knowledge on the numerous techniques and sensory mechanisms on which animals rely for orientation or navigation. Maps for the blind may show regions or routes, they may be for static or mobile use, and they may be spatially or verbally formulated, (Leonard[278]). Blind people were able to follow a maze better when a tactual map was added to verbal directions (Maglione[279]), and could discriminate tactual symbols presented in the context of a tactual map (James and Dill[280]).

Mental Maps

Mental maps play an important part in geographical orientation. Adequate geographical orientation requires the individual to be aware of his position in relation to features both within and beyond his visual field. Spatial information sensed directly must be related to a wider frame of reference stored in memory as a topographical schema or mental map.

Early studies of orientation distinguished between mental maps based on compass directions and those related to home, the latter being associated with children and primitive peoples (Trowbridge[281]). Certain early maze learning studies suggested that a sequence of movements is learned, rather than maintaining a continuous notion of relative position within a larger frame of reference (Brown[282]). Other findings implied the existence of mental maps for larger areas than could immediately be perceived (Woodring[283]). High[284] required subjects facing north to indicate the compass heading of various cities, but his explanation for his finding of greater accuracy for more distant locations, in terms of the street lay-out of the towns where the experiment took place, seems unsatisfactory and an illogical deduction from the measurements. Studies of orientation using a rotating chair (Witkin[285]) and body tilt (Day and Wade[286]) are more normally ascribed to spatial orientation, even though the former specifically referred to geographical orientation in its title. In these studies orientation was influenced by the perceived rotation of a pattern, although such studies also typically refer to spatial rather than geographical orientation (Taylor[287]).

The recent resurgence of interest in mental maps particularly among geographers (Ittleson[288]; Gould and White[82]; Stea and Downs[289]) does not imply that significant progress in understanding or making use of mental maps has been achieved, except in very limited applications. A recent text on 'Topographical Orientation' (Downs and Stea[290]) reproduced an article which appeared 25 years before (Griffin[88]), and its continued pertinence does not point to major advances in the intervening period. A mental map, or topographical schema, reflects the psychological importance of its contents and often distorts geographical reality. Good orientation implies close correspondence between the schema and the map, and maintaining a sense of direction implies continuity and expansion of the schema. Dornbach[291] remarked that the better the mental map established through preflight study, the easier and more accurate the subsequent navigation. He wondered how this might be turned to advantage by using auditory cues to supplement or trigger remembered images. Griffin[88] also noted the relevance of non-visual cues to mental images. While mental maps may be formed of places never seen, some individuals seem incapable of retaining or forming adequate mental maps (Dornbach[292]). Shaller[293] compiled anecdotal evidence on why aircrew become disorientated or how they could be correctly reorientated.

Some of the literature on the representation of mental maps has been reviewed by Gould and White[82] and by Canter[294]. Elsewhere, the former have discussed a variety of possible techniques for studying mental maps, including projective ones (Goud[295]). Saarinen[296] has also reported studies using projective techniques. The parallel literature on spatial cognition was reviewed by Hart and Moore[297,298]) in relation to maturation and to the everyday environment. They attempted to explain experimental findings in terms of theoretical concepts, such as Piaget's developmental ideas (Beard[299]) and the sensory-tonic theory of Werner and Wapner[300]. Riffel[264] has also considered Piaget's ideas on egocentricism-decentration in relation to children learning to read.

The major methodological problems in studying mental maps are how to externalise mental maps for public scrutiny and how to aggregate individuals' maps to arrive at a general consensus. A variety of projective tests have been used to externalise mental maps: open-ended or expressive procedures requiring verbal or graphic reproductions, and more directed techniques such as ordering specified places on relevant criteria or using psychophysical techniques and rating scales to quantify certain aspects such as distance, military importance, or political, social and economic desirability. Directed tests tend to be less sensitive to displacements and distortions of space, but their major methodological advantage lies in the ease of quantification, aggregation and analysis. Factor analysis has been used to aggregate individual's responses but this generates a number of solutions each requiring individual psychological interpretation, (Taylor[222]). In general, other studies have obtained pointing or direction indicating responses from subjects, but the reliability of the results largely depended on the conditions under which the data were obtained (Lichte et al.[56]). There are intransigent difficulties in any method for depicting or representing the mental maps of one person in a form which is intelligible to others, since the process of depiction lends a spurious precision, permanence, stability and cohesion to a fluid, changing and often amorphous process.

Military Studies

A study of Naval aviation cadets by Clark and Malone[301] suggested that geographical orientation was not related to spatial visualisation or spatial orientation in that low and generally insignificant correlations among these measures were obtained. Among cadets good geographical orientation was positively related to the use of mental maps, to travel experience, to ability to visualise the Earth, and to comparative lack of education. Large individual differences tend to be found on tests of geographical orientation (Clarke and Malone[301]; High[284]). Findley et al.[249] sought to identify the most important skills for effective land navigation, and in general found that compass skills were less relevant than such location skills as direction estimation and visualising terrain from contour lines. In a series of studies of land navigation ability, Powers[302,303,304] used job description methods to identify several basic navigational skills, and tested the effects of eight terrain factors on navigational performance. He developed and validated a programme of instruction in advanced land navigation which demonstrated that relatively unskilled men could be trained to find their way successfully in poor visibility over unfamiliar terrain, provided that the correct navigation techniques were used.

In studying aspects of geographical orientation, a comparative approach has often been adopted, with differences in performance related to the method of displaying the map, (e.g. Laymon[305]; McKechnie[306]; Payne[307]); to map scale (e.g. Edmonds and Wright[308]); or to reprographic techniques and level of cartographic annotation (e.g. Hill[309]). Another approach has been to study a category of accidents in which navigational errors were implicated (collisions with high ground (Ruffell-Smith[310]). It was held that the accidents would have been prevented by a pictorial navigation display

providing the pilot in immediately comprehensible form with the information normally computed for him by the navigator. Bard[311] concluded, from reviewing the causes of disorientation which could be ascribed to deficiencies in maps and navigation displays, that automated moving map displays would reduce disorientation significantly.

Some studies have been concerned more specifically with the recalcitrant problems of adequate mapping in order to maintain geographical orientation in low altitude flight. This has been considered within the broad context of other related problems (Miller[312]; McGrath[313]), in terms of the need to link operational requirments, map design and production, and international and interservice co-ordination (Wright[314]), and in relation to special purpose radar maps emphasising the operational need to maintain geographical orientation (Emery[315]).

McGrath and his colleagues conducted an extensive research programme on aspects of geographical orientation, being primarily concerned with low altitude flight, having established the paucity of existing knowledge by means of a literature survey (McGrath and Borden[65]). McGrath[316] defined the operational problem, suggested the role of research and the main research issues, indicated alternative research methods, and outlined a comprehensive programme of research, progressing from simple to complex film studies, through existing to specially constructed terrain model simulation studies, with field studies to check the laboratory findings (McGrath and Borden[65]). Pilots found it difficult to plot ground track on charts using film material (McGrath and Borden[317]), and performance in maintaining orientation was not affected either by the removal of placenames from a chart nor by change in scale, although a change of scale and of information content did affect performance, (McGrath, Osterhoff and Borden[132]). The film method was elaborated by means of synchronising cockpit instruments with the film, and giving the pilot control over the speed of both, producing better geographical orientation (McGrath, Osterhoff, Seltzer and Borden[318]). A subsequent finding of orientation being affected by scale proved to depend upon the particular route flown, and was interpreted in terms of the choice of appropriate orientation strategies (McGrath, Osterhoff and Borden[319]). Development of a theoretical model based on these findings led to the conclusion that the effectiveness of charts with a given specification is terrain dependent (Osterhoff and McGrath[133]). It is also dependent on the retention of colour coding (Osterhoff, Earl and McGrath[320]).

The above studies on maps were complemented by a series of simulation studies on other aspects of geographical orientation, including speed control inversion as a source of navigational errors (McGrath, Christensen and Osterhoff[321]), and accuracy of target location when performed by a plotter relying on the pilot's spoken messages (McGrath, Earl and Osterhoff[322]). Borden[323] showed that pilots could report their track, elapsed time on track, use of checkpoints and awareness of geographical orientation retrospectively after landing, and subsequently he confirmed, by comparing actual tracks flown with the pilot's recollections of them, that these reports provided an accurate and valid method of assessing navigation performance (Borden and McGrath[324]). The same authors categorised numerous visual checkpoints visible on film in terms of pilots' judgements of their visual and cartographic utility and their frequency of occurrence (McGrath and Borden[121]). The results could be interpreted in terms of the pilots' ability to interpret maps, the cartographer's choice of map features, the empirical factors determining the best checkpoints, and the pilots' ability to learn how to choose them. Subsequently, verification was obtained by a simulation study which compared standard charts with an experimental chart compiled according to the criteria for choosing the best checkpoints. The latter reduced orientation errors and improved pilots' ability to fix their positions positively, (McGrath and Osterhoff[325]). The findings from these and other experiments are summarised in a paper by McGrath[326] at a JANAIR Symposium (McGrath (ed.)[69]), in which recommendations for improving geographical orientation during low level flight were made.

Having reviewed the literature on geographic orientation in humans, Lichte et al.[56] arrived at the following conclusions:

(1) There is no innate sense of direction nor ability to maintain orientation.

(2) There is no learned or unlearned ability to know or maintain a sense of direction through unknown senses, such as responses to the earth's magnetism or to the polarisation of light.

(3) Orientation begins with information being sensed directly from the environment which is used to determine spatial relationships with the visual field. The visual field is then extended by imagination to include areas beyond the immediately sensed, and the individual perceives his location as geographical co-ordinates within this wider, imaginary space. Thereafter, a sense of direction and geographical orientation is maintained by continuous awareness of movements and positions in this space, and by awareness of spatial relationships between new and familiar regions. This skill improves with practice and the experienced individual needs to devote very little attention to the process, in order to remain oriented under normal circumstances.

(4) When unrecognised errors are made, those factors that normally lead to a confident, complete and persistent correct orientation, tend to produce equally confident but completely incorrect orientation, with the same degree of persistence.

(5) Individuals differ in their orientation ability, both in terms of the extent or scope of their orientation and in their ability to maintain orientation and recover orientation once they have been disorientated.

In relation to the particular problems of navigating aircraft, the following points have been identified from examination of aircraft accident and incident reports (McGrath and Borden[63]; Taylor[327]).

(1) Disorientation is an insidious process, that can persist for long periods of time without the pilot realising he is lost. Wanting to believe that the aircraft is still on the planned tracks leads the pilot to develop expectancies about what he will see outside the aircraft and false hypotheses are often made about the identity of features on the ground. These erroneous identifications are maintained despite much contradictory information.

(2) The experience of geographical disorientation can be so compelling that the pilot can become absolutely convinced that his instruments or maps are wrong and formerly familiar surroundings can suddenly appear unfamiliar.

(3) Conflicting cues under geographical disorientation can produce marked emotional stress, confusion and pre-occupation.

As a consequence of the high speeds of aircraft, navigation errors caused by geographical disorientation tend to be large. One of the major tasks of navigation training is to teach "lost procedures" for quickly reorientating pilots who have become disorientated before the situation becomes irrecoverable. These procedures require ground-to-map comparisons, rather than the normal map-to-ground scanning because the position on the map is unknown.

CHAPTER 4

OPERATIONAL REQUIREMENTS FOR AVIATION MAPS

4a CURRENT OPERATIONAL DEMANDS

Fundamental Problems

There has generally been poor communication between map producers and map users about their respective requirements and limitations. Thus, the importance has often been voiced of matching aviation maps with the needs of the user. How this should be done is seldom clearly stated, however, and proposals have often taken the form of suggestions by articulate users based on their personal experience, without a scientific basis and with no indication of how typical their requirements may be. In considering why the "perfect air map" does not exist, Chichester[17] summarised three main reasons for this failure:

"(1) Maps are designed by highly skilled specialists who, however, do not generally know from first hand experience what the practical requirements are. They rely on hearing of these from practical airmen.

(2) The better the practical men are at map reading the less able they are to put into words how they set about it and what is required for the ideal air map.

(3) Map production is extremely expensive in time, work and materials with the result that map makers are loath to scrap a map once made, if it will 'do', even though they realise it might be improved."

This may be an oversimplification of a highly complex problem, but these three basic considerations underlie many of the map requirement problems that aviation cartography faces today. An additional consideration is that operational demands on the one hand, and display technology on the other, often advance or change at a pace which cartographic production methods cannot match. Consequently, even when needs have been identified and clearly stated there has been a lag in meeting them.

It was acknowledged from the outset that the aviator had specific cartographic requirements and there was quite a rapid development from overprinting topographical maps with navigational information to evolving special navigation charts (Meine[5]) to meet the requirements of aviation at an international level, with agreed standards on choice and format of depicted navigational information (Lees[9]). Chichester[17] stating his personal view on how to design the ideal air map enumerated four principles that would still be acknowledged today, albeit in a modified form:

(1) The map should show everything that will be needed and omit everything that will not. He noted that it is in the latter respect that air maps usually fail, because "the designer cannot screw up the courage to leave things out and the practical men do not press him to do so". No feature, he argued, is of value unless it is distinctive, if not unique, within the area of uncertainty covered by the map; the less that can be shown on the map the easier it can be to read, provided that nothing necessary is omitted.

(2) All features that are shown must be mapped accurately.

(3) The smaller the scale the more valuable the map, provided that the two principles above are adhered to. This minimises handling problems and, more importantly, makes it easier to assess the general characteristics of the terrain.

(4) The prominence given to features on the map should match their prominence when viewed from the air.

Touching on another fundamental issue, Chichester noted that for ideal maps, each sheet should be separately designed for the area it covered; but, as the differences between adjacent dissimilar sheets might confuse the map reader, he concluded that a standard specification should be followed that includes the requirements of all the sheets in the series. The practical difficulties in attaining these principles have proved to be at best daunting and at worst insuperable. It is not a simple task to define information as either necessary or unnecessary, or to emphasise visually on the map what is visible from the air and what is useful because of its rarity or uniqueness. There is also the question of whether the requirements for a navigator as skilled as Chichester would suffice for unskilled novices.

Methods for Establishing Requirements

Today, responsibilities for identifying, and methods for defining, operational requirements for aviation cartography are complex and vary in different production organisations. The method used by the largest production agency, the US Aeronautical Chart and Information Centre (ACIC) has been described by Cummins[328]. The ACIC Requirements Process has the following stages:

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(1) Evaluating the need.
(2) Establishing it as a firm requirement.
(3) Authorising resources for its design, testing, production and distribution.
(4) Establishing procedures for maintaining its currency and improving its design.
(5) Directing a periodic review of the requirement for revalidation or cancellation.

Once the need for cartographic support of a user requirement has been validated, a joint cartographic-military team carries out an analysis of the factors which may affect the type of product or data required. Typical "operational requirement" factors analysed include the type of mission, accuracy tolerances, navigational or guidance system components, navigational techniques, and human engineering considerations such as cockpit or work area size. Production factors are also analysed. Following the production and evaluation of a prototype, a detailed Requirement Guide is formulated including a description of the requirement, the mission and equipment considerations, usage factors, the accuracies required, significant dates, and specific technical information including the projection, scale, content, coding, format and revision cycle. Periodic revalidations of the requirements are carried out in Product Reviews which record the continuing need, modification or cancellation of requirements.

Experience has shown that the best requirements investigation units include both cartographers and military officers. The methods available to such requirements teams for determining the user needs are various, but surveys and interviews with users are most commonly used (Cummins[328]).

Four different methods for determining map user needs have been distinguished (Bard et al.[152]):

(1) Use of questionnaires to be completed by aircrew.
(2) A controlled debriefing following operations and training missions.
(3) Performance measurement on simulators, terrain models, or film.
(4) Performance of controlled missions by either automatic inflight recordings, tracking systems, or trained observers.

This classification omits interviews, whether structured or informal, and discussions and conferences between user representatives, producers and cartographers, which have a great bearing on most requirements issues. No single method is likely to suffice; an approach using several methods should give the best results.

Systems engineering techniques, such as functional analysis, decision analysis, flow analysis, job analysis, and design checklists may have a contribution to make to assessments of map requirements (e.g. Morgan et al.[74]; Singleton[110]). Although their relevance has been acknowledged (Bishop et al.[22]; Dornbach[127]), in practice map requirements tend to be identified using procedures that have evolved in cartography, independent from systems engineering.

Classifications of Requirements

Since 1948, users of aviation cartography have extended far beyond the comparatively limited audience to which Chichester addressed his paper. Meine[5], classified the whole of modern aviation cartography in terms of six user requirement areas:

(1) Maps and charts for civilian traffic services and traffic control.
(2) Maps and charts for military purposes, mainly navigational.
(3) Air line maps for traffic systems and navigation aids.
(4) Thematic maps of air transport, based mainly on statistics.
(5) Maps for air passengers.
(6) Maps for space flight, including the Lunar, Mercury and Gemini charts.

Alternatively, Meine suggested, three broad distinctions could be made in terms of the "operation" of aircraft. These are as follows:

(1) Navigation, including visual navigation, instrument navigation, approach and landing charts, plotting charts.
(2) Traffic control, in the lower and upper airspace, and for planning.
(3) Thematic investigations, including air traffic density, frequency of flights, passengers and mail load, air transport capacity.

Numerous other classifications of operational factors can be made that have associated cartographic requirements for map information content, legibility and geodetic accuracy. Categorisations of operational factors include:

(1) Day or night flight. External visibility affects requirements for map content. The method of illumination used for map reading at night (dim or bright, red or white) has important consequences for map legibility.

(2) Visual Flight Rules (VFR) or Instrument Flight Rules (IFR). Often associated with day or night flights, VFR/IFR procedures have different requirements for map content and geodetic accuracy. Topographical information is essential for VFR conditions; radio facilities information is essential for IFR conditions. Greater geodetic accuracy is necessary on maps for VFR en route navigation than on IFR en route charts.

(3) Flight Phase. Content, legibility and accuracy requirements vary between pre-flight planning, en route, approach and landing phases of most aircraft missions.

(4) Flight profile. Characteristics of the aircraft's flight profile, such as high or low speed, high, medium or low altitude, determine the visibility of topographical features, and hence the requirments for map content. Legibility requirements vary as a function of time pressure and navigation workload. Accuracy requirements also vary with the navigation technique adopted.

(5) Operational Role. Distinctions between the type of mission being flown, such as between strike, reconnaissance, ground support, maritime, and tactical transport support have important consequences for content, accuracy and, to a lesser extent, map legibility requirements.

(6) Crew Constitution. In single-seat aircraft less time is available for map reading compared with two-crew operations. Map content and legibility factors are likely to become more critical as the time available for map reading is reduced.

(7) Type of Aircraft and Navigation System. The provision of avionics, radar, radio facilities, and automatic map displays affect cartographic requirements for content and accuracy. In particular, map displays and hand held maps have different legibility requirements.

Specific Operational Requirements

High Speed, High Altitude Flight

A series of comparatively early studies sought to apply the systems analytical approach to chart specifications for high speed, high altitude flight (Waters and Bishop[23]). The operational requirements of faster aircraft implied a reduction of map scale without a commensurate reduction in map detail, and many of the most familiar cartographic problems, of selection, choice of symbols, generalisation, and prominence of detail, had to be resolved (Anderson[329]: Miller[41]).

Kishler et al.[20] reviewed the development and current status of maps and charts for high speed high altitude navigation in the early 1950s. They criticised the proliferation of charts that had to be carried, producing handling and storage problems, they commented on their lack of integration and their considerable overlap in terms of functions and content, and they described the charts as too cluttered for rapid reading. Interviews, questionnaires and objective performance tests all helped the authors to identify deficiencies in existing charts and to propose improvements for future charts to meet envisaged high speed high level requirements.

In developing a specification for an aeronautical chart intended for high altitude, single pilot operations (the US Navy XDA-93-1 Chart), the same group of workers at Dunlap & Associates Inc. (Bishop et al.[22]) carried out a job analysis of the pilot's task based on subjective data, and concluded that the content of the chart could be determined from five categories of information:

(1) The operational characteristics of the aircraft, e.g. speed, altitude and duration of flight
(2) The facilities carried by the aircraft, e.g. navigation equipment, navigator.
(3) The mission of the flight, e.g. attacking a target, reconnaissance, interception, each requiring different navigation precision.
(4) The nagivation facilities on the ground, e.g. radio ranges, marker beacons, cultural features.
(5) The navigator's performance, e.g. workload, flight stress, detection of ground features.

Using these categories of information, they provided a tabulated breakdown of the pilot's task and the associated functional requirements for the navigation chart. For instance:

Operational Characteristics:	*Functional Requirement for Navigation Chart*
Speed: 400–700 knots	Checkpoints should be placed approximately every 125 to 160 miles (every 15 to 20 minutes of flight)
Pilot's Task: Pilot must fly as well as navigate; this may occur under adverse conditions due to stress of temperature, oxygen lack, etc.	Items should be shown as they are perceived and in relative contrast representative of their importance in the whole navigational problem. Symbols on the chart should be obvious and not require explanatory legends. Chart should be suitable for use in adverse conditions.

A primary feature of the XDA-93-1 Chart was the comparatively small size, approximately 16 x 19 inches, and small scale, 1:4,337,740 (1 in = 60 NM) compared with the 1937 Regional Aeronautical Chart and 1943 World Aeronautical Chart at 1:1,000,000.

Kishler et al.[20] also came to the conclusion that in addition to a special chart, pilots on high speed, high altitude missions required a tabular form containing essential radio navigation information. This was developed in parallel to the XDA-93-1, and it was to present in an organised format all his pre-flight planning information required for successful completion of his mission, such as fixes, fuel state, wind, drift and electronic aids information. The form and its development are described in detail by Cramer et al.[330].

Subsequent evaluations of the US Navy XDA-93-1 Chart are reported by Koponen et al.[331], Murray et al.[128], Murray and Waters[27], Murray[28], and Schreiber. Subjective and objective assessments were made under different viewing conditions (red light and white light) using different groups of subjects (pilots and college students). Generally the XDA chart was found to be superior to the existing WAC chart, but not significantly better than a similar experiment chart produced by the USAF, known as the XJN Chart (Murray[28]). The USAF XJN was eventually developed into the Jet Navigation (JN) Chart at 1:2,000,000 scale. Unlike the XJN, information was not printed on the back. The sheet size was comparatively large, approximately 42 x 58 inches, but it was intended that the chart should be cut into strips 12 inches wide for specific flights.

The same group of authors also considered how various kinds of information, such as mathematical and meteorological data, could improve chart construction (Waters and Orlansky[24]; Waters[332]). They produced a set of formulae, tables, graphs and nomographs to be used by the cartographer for selecting features on the basis of the size of the object, its visual contrast with the background and the effect of atmospheric conditions and related conditions applicable to a particular mission. In addition to mathematical and meteorological criteria, they considered that the important psychological criteria for selection were threefold:

(1) The pilot must be able to see, discriminate and identify the selected features.

(2) The properties of the object that make it visible are its size and contrast with the background, and its pattern, contour or shape.

(3) The object must be represented by a symbol, form or colour that most nearly approaches the actual appearance of the object. Symbol design factors were the subject of a separate study (Koponen et al.[29]).

JN was extensively evaluated in the field by questionnaire and interview techniques and a high degree of user acceptance was achieved (McGill and Cain[26]; Lichte et al.[56]).

High Speed Low Altitude Flight

Historically, the navigational problems of low level flight have received most cartographic attention, in relation to both high and low speed. Price and Older sought to define the main determinants of successful high speed navigation at very low altitudes, with a view to specifying appropriate aids and training. They concluded that the best solution combined briefing aids, operational aids, and devices specific to high speed low level missions. Miller[334] reviewed the visual display and control problems associated with high speed low altitude flight and the provision of appropriate mapping was regarded as an important aspect. A more detailed discussion of visual problems is given by Mercier et al.[335].

Summerson[122] categorised ground features in terms of their frequency, recognisability, association with probable flight paths, and consequent suitability for high speed low level charts. The portrayal of obstacles was recognised as being vitally important as compared with high altitude chart requirements. McGrath and Borden[121] and McGrath and Osterhoff[325] reported similar analyses based on assessments of the visibility of terrain features viewed on film of high speed low level missions. Operational requirements for recognition, navigation, workload and planning in relation to chart design were considered by Howey[336] who included user comments on experimental charts. More recently, Pelton and Magorian[337] emphasised the limitations imposed by poor visual navigation capability and inadequate maps on high speed low level missions, in relation to mission and route planning, to choice and location of en route checkpoints, and to terrain depiction and recognition. They also discussed problems of utilising terrain features as aids to planning and fulfilling a mission. They concluded that the primary types of information required for high speed, low altitude missions were:

(1) Data regarding the planned route.

(2) Checkpoints which can be acquired and accurately located from the aircraft.

(3) General terrain shape and water features with significant recognisable terrain features readily interpretable.

Inability to meet the requirements for route planning and tactical information has been a major inadequacy of moving map displays. These use microfilm and optical projection techniques, and have largely been developed to reduce the navigation workload. Methods of annotating microfilms have been evaluated, but none has so far proved practical. At the present time, pilots in aircraft with moving map displays carry an annotated hand-held chart showing this information and which they correlate in flight with the aircraft's position indicated on the map display (Taylor[338]).

The importance of the correct selection of visual checkpoints for successful high speed low level navigation has been borne out by subsequent research (McGrath and Borden; McGrath[339]). In flight, the pilot has little time available for map reading and has to scan the map in short glances lasting between 1 and 3 seconds. Cluttered maps that rely on the user to sort the relevant information from the irrelevant therefore tend to be unpopular for high speed low level missions,

particularly in single seat aircraft (Murrell[131]; Lakin[340]; Taylor[222]). 1:250,000 scale maps may have sufficient accuracy and detail for high speed low level missions, but contain so much irrelevant information and clutter that many pilots prefer to use less accurate 1:500,000 mapping where the content is more selective and better matched to their needs. An analysis of the human factors criteria affecting the design and content of the USAF 1:500,000 Pilotage Chart, intended for high speed low level flight and precursor to the current Tactical Pilotage Chart Series, is given by Dornbach[127]. Kihl and Long[341] give a similar description of Canadian 1:500,000 charts for high speed low level operations.

Terrain representation has been of major concern since the earliest attempts to design maps for high speed low level flight. Initially, cartographers were concerned with the ability to match the map with radar information as well as for direct visual contact. Features were selected according to their radar significance, and the terrain was represented by the slope zone shading technique, whereby the pattern of slopes was shown in grades of white (Miller et al.[42]; Miller and Summerson[342]; Angwin[343,60,61]). Whilst radar map matching in low level flight is still the subject of cartographic research, albeit with optically superimposed images (Brad[344]; Barratt et al.[345]), most current 1:250,000 and 1:500,000 maps for high speed low level users portray terrain shape by some combination of hill shading and layer tinting. Nevertheless, inadequate relief representation is frequently one of the most serious criticisms of these maps voiced by aircrew.

In addition to the three factors enumerated by Pelton and Magorian[337], aircraft type, equipment, workspace, navigational aids and mission were noted by Davis[346] as operational factors introducing technical design limitations for aeronautical charts intended for low altitude high speed flight. At low altitudes environmental stresses, such as vibration and turbulence, are more severe and they have important consequences for map legibility. Increased importance placed on maintaining night vision sensitivity also introduces severe constraints on map illumination that are not present at higher altitudes. The need to reduce the number of charts required for a mission was a major stimulus to the development of moving map displays and microfilm storage techniques. Also, in peace time, the provision of air-overprint information pertaining to low-flying restrictions, routes etc. is an important factor that has contributed to the popularity of the 1:500,000 Low Flying Chart series produced by RAF Germany for North-West Europe (Wright[347]; Taylor[348]).

Low Speed Low Altitude Flight

In a survey, carried out by the US Human Resources Research Organisation under the project Lowentry, Wright and Pauley[349] listed the following major operational and environmental considerations relevant to low speed low altitude tactical navigation in helicopters, also known as "nap-of-the-earth" flying.

(1) Rapid reaction missions with little or no planning.

(2) Low obstacle clearance that limits the area of the terrain in view and restricts the time that attention can be directed inside the cockpit.

(3) Planimetric, flat, features in view for very short times; tall, vertical features and relief in view for longer times.

(4) Correlation of terrain and map achieved only by "time-based reconstruction of momentarily viewed features".

(5) Comparatively large operational area with limited ability to predict the direction of the next mission.

(6) Operation over terrain varying in familiarity.

(7) High accuracy needed in approaching a destination.

(8) High precision needed in timing arrival at the destination.

(9) Maximising speed in transition.

(10) Operations in darkness and limited visibility.

(11) Storage retrieval and handling problems with maps

(12) Restricted choice of map scales, either 1:50,000 or 1:250,000.

(13) Unintegrated cockpit.

(14) No automatic navigational data processor.

(15) High workload.

More recently, Barnard et al.[129] also emphasised the severe restriction on map reading time caused by maintaining a constant lookout for obstacles, and they referred to the degradation in flying and navigation performance caused by the added stress and fatigue associated with flight at very low levels.

Both Wright and Pauley[349] and Barnard et al.[129] give detailed analyses of the low level navigation task, the former based primarily on a study of training and instructional manuals, and the latter derived from interviews and surveys of operational aircrew. Pre-flight planning and terrain familiarisation play a highly important role; as planning time or familiarisation is increased, the accuracy of low level navigation performance also increases and acceptable performance is usually attainable, even with poor cartographic support. However, cartographic factors become critical when the terrain is unfamiliar and when a quick response is called for, with little time for planning.

Training factors were studied under the Lowentry project. Waller and Wright[350] found that a small amount of training can improve the accuracy of angle of drift estimation from maps; Gray et al.[351] found a similar effect of training on the ability to estimate directions from maps, although the improvement was small and unlikely to be operationally significant.

The problems of handling and storing maps in the cockpit have led to elaborate techniques being taught for folding tactical maps (Harter[352]). Ultimately, the best, though not necessarily essential, solution to this and other low level navigation problems lies with the provision of automatic map displays (Bass[353]). A trial, comparing an automatic navigational system including a projected map display with conventional navigation with a hand-held map, found that, while the hand-held system was better, occasionally pilots became completely lost with it, and that the main benefits of the automated system were in permitting revised routeings to alternative destinations and allowing effective updating of the automated system according to recognised landmarks (Lewis and Anderson[354,355]). Whilst the merits of moving map displays for helicopter operations in terms of navigation performance seem clear, few rotary-wing aircraft are fitted with advanced navigation systems, and research programmes to evaluate alternative systems are still being proposed (McGrath[356]). In the meantime, the navigation task tends to be accomplished by dividing the workload between two crew members – the pilot and his co-pilot, observer or gunner. An early study of dual versus solo pilot performance in low level helicopter missions showed only marginal benefits in terms of landing errors, smaller initial heading errors and fewer en route let-downs (Lewis et al.[357]). However, the method of evaluation of low level navigation performance seems to be critical, and the high accident risk results in a necessary trade-off between what can be achieved in the laboratory and what can be achieved by flight trials (Farrell[358]; Lewis[359]). Head and eye movement records taken in fixed wing aircraft during low level navigation over unfamiliar terrain at minimum clearances or at 25 feet above obstacles indicated that about 27% of the time was spent map reading. Four seconds was the maximum glance time; and glances seldom exceeded 2.5 seconds (Lewis[66]; Lewis and de la Riviere[360]). Lovesey[361] found that in shorter helicopter sorties pilots looked out of the cockpit 85% of the time. However, Strother[362] found that the visual scan techniques of the experienced helicopter pilot change dramatically as a function of the altitude and manoeuvre and that he made much use of peripheral cues.

The consequences of these operational factors for the design of maps for low speed, low altitude flight have been considered in a specification for a helicopter pilotage map for marine assault missions proposed by Bishop et al.[126]. This report is reproduced, with annotations, by Wright and Pauley[349], and forms the basis of many of their recommendations for a general purpose army low level navigation map. Wright and Pauley[349] concluded that the optimum scale for low speed low altitude army aviation was between 1:100,000 and 1:50,000. Standard maps at 1:50,000 and 1:250,000 scale are either too large and create handling difficulties, or too small with consequent lack of detail. Some of the cartographic requirements were reported in an earlier paper (Wright[363]). These may be listed as follows:

(1) A single, multi-scale format to satisfy the basic requirements of all the elements in a tactical operation including ground and air forces.

(2) Uniform detail, rather than emphasis of the outstanding structure.

(3) A perceptual format for relief information, with contour lines added to give necessary relief detail.

(4) Stream lines and ridge lines which define relief highs and lows.

(5) A geometric progression for coding elevation to emphasise small changes in flat terrain and large changes in hilly terrain.

(6) Clearly defined edges to vegetation, with less emphasis on the interior.

(7) An automatic map display system, allowing time-of-postion navigation procedures, immediate tactical responsiveness and ease of updating, and changing in the field.

4b MULTIPLE FUNCTIONS OF EXISTING MAPS

In the field of cartography, aeronautcial charts are considered to be examples of special-purpose maps, as distinct from general-purpose maps such as atlases and conventional land mapping (Keates[120]). In the broader field of information display, aeronautical charts are typically regarded as multi-purpose displays, meeting the needs of a variety of users and of tasks, contrasting with, say, altimeters, or speed indicators which meet comparatively specific needs. Numerous tasks in aviation require maps; any single map can be seen to fulfil more than one simple function.

Inspection of the contents of Annex 4 to the ICAO Convention on civil aviation reveals a proliferation of chart types with differing functions. Included in Annex 4 are: aerodrome obstruction charts; plotting charts; radio-navigation charts; terminal area charts; instrument approach charts; world aeronautical charts at 1:1,000,000; aeronautical charts at 1:500,000; visual approach charts; landing charts; aerodrome charts; and aeronautical navigation charts at 1:2,000,000. In many cases, particularly those related to the air traffic services, radio aids to navigation, terminal areas, aerodrome layout and approach landing and departure procedures, their functions are comparatively circumscribed. On the other hand, many different kinds of information are depicted on these charts, according to ICAO or Military Standard Specifications, each with separate advisory functions. Control zones around airfields are defined, airways and terminal areas are designated by international number systems, reporting points and advisory routes are identified by radio facility symbols, and obstruction heights and terrain elevations are indicated in feet. With this information the navigator can check the aircraft's flight path and height above the ground, he can identify the location of obstructions and danger areas, and he can check his distance from other aircraft, reporting points and his destination.

For en route navigation, functional distinctions may be drawn between charts designed for instrument flight rule (IFR) operations on civil airways, and for visual flight rule (VFR) operations in military and general aviation. Some of

these are listed in Figure 3. In practice most visual navigation charts display information concerning radio aids to navigation, and, to a smaller extent, many instrument navigation charts have visual navigation capabilities by depicting a skeletal topographical base, such as coastlines, and major water features.

Visual navigation charts tend to have wider applications than instrument navigation charts and the variety of their functions tends to increase with their scale and their information content.

1. 1:250,000 Maps

The series 1501-Air Joint Operations Graphic is the first 1:250,000 air chart to be produced world wide by NATO mapping agencies. The JOG is designed as a 1:250,000 land map and aeronautical chart suitable for air and ground forces. It is published in three versions: JOG-Air, JOG-Ground and JOG-Radar. On the Air version, measurements are in feet with a stable air overprint. On the Ground version, measurements are in metres with a limited air overprint (Bennett et al.[114]; Self[364]). A 1:250,000 land map and air chart with a common topographic base has numerous potential applications. Bennett et al.[114] listed these as follows:–

(1) By Land Forces for:–

- (a) Tactical and Logistic Planning
- (b) Briefing Intelligence and Wall Map
- (c) Close Support by Air Forces
- (d) Tactical Operations, including Route Map.

(2) By Air Forces for:–

- (a) Close Support of Land Forces
- (b) Low Level Strike and Reconnaissance
- (c) Tactical Transport Support Operations
- (d) Helicopter Support Operations
- (e) Low Level Route Map
- (f) Army Air Corps Use.

Although these functions were all seen as potential applications for the JOG, in practice, a 1:250,000 topographical map was found by Lakin[340] to be an essential requirement only in the following air roles:–

(1) In training for low altitude flight en route and for approach to targets, landing places or dropping zones.

(2) In air defence for approach to and identification of landing places.

(3) In tactical transport during low altitude flight en route.

(4) In helicopters during flight en route at all altitudes.

The major problem with multi-purpose maps, such as the JOG, is that the information content tends to be determined by the minimum requirements of each user. Consequently, most users tend to have more information displayed than they require, and in extreme cases, the map will be cluttered with irrelevant information and map reading may become difficult or even impossible. This proved to be the case with the JOG with regard to the critical air requirement for 1:250,000 mapping in low level, high speed operations. Following criticisms by low level users, recent revisions to the JOG-Air, incorporated in the 4th edition specification, have removed much of the information not needed in this role. The map now has a cleaner and less cluttered appearance but the effects of this reduction in content on other user applications have yet to be assessed. It seems likely that other special-use variants will be produced in the future, by selective deletion and addition as the individual requirements become more refined and differentiated. A helicopter variant has already been produced in Europe for evaluation.

The map production process divides the information content of the map into separate printing components, and therefore readily lends itself to selective deletion and addition of information held on these components, such as the JOG-Air information overprint. Modification of content within components requires more cartographic effort. Inevitably, the proliferation of variants will introduce production, planning, storage and distribution problems, but these extra costs must be weighed against the improved value of the product to each user.

2. 1:500,000 Maps

World-wide 1:500,000 air mapping is currently provided by the Tactical Pilotage Chart (TPC) series. This replaced the US Pilotage Chart (PC) series and UK Topographic Tactical Chart (TTC) series in the period in 1966–67 as part of the same international standardisation production programme as the JOG. 1:500,000 is the standard scale of mapping for tactical air forces. The sheet size, coding and content of the earlier PC and TTC series were designed for moderate speed aircraft operating at medium to high altitudes. The TPC was designed for use by high performance all-weather tactical aircraft using radar with the emphasis on low-altitude operations. The TPC sheet size covers four times the area of the old PC sheet in order to reduce the number of sheets required for a single mission. Pictorial symbols were used to depict landmark features suitable for checkpoints during low altitude, high speed flight. Obstructions and power line data were shown, and relief was represented by a pictorial format of layers, hill shading and contours to give a ready appreciation

of the shape of the terrain as seen at low altitude. Other features were included which had become regarded as essential on a low level chart, such as emphasised drainage and railways, maximum elevation figures, and a comprehensive aeronautical overprint including restricted airspace (Bard[365]; Harvatt[14]; Self[364]).

In North West Europe a special variant of the TPC is produced by the UK Directorate of Military Survey, known as the Low Flying Chart (LFC). This uses the TPC topographical base repromats, printed in slightly changed colours, with a detailed multi-coloured operprint of low flying information relevant to peace-time training operations in Europe, such as low flying routes, controlled and restricted airspace, and danger areas.

3. 1:1,000,000 Maps

The 1:1,000,000 Operational Navigation Chart (ONC) completes the family of world-wide aeronautical charts produced under the same national standardisation and co-operation programmes as the JOG and the TPC. The ONC began to replace previous US 1:1,000,000 World Aeronautical Chart (WAC) in 1959, and in 1966–67 it merged with the UK Tactical Navigation Chart (TNC) under a common specification.

Replacement of the WAC by the ONC was a result of the increased emphasis on low altitude operations with radar aids in strategic air operations (Bard[365]). The ONC was designed with similar characteristics as the TPC, such as emphasised railway, drainage and roads, more detailed contouring, and pictorial landmark features, and each sheet gave four times the area coverage of the WAC sheet. Maximum elevation of figures were used, centred within 1 degree quadrangles to indicate the maximum terrain height and hence the pilot's safety altitude in emergency.

A new form of relief layering, used on the ONC but not on the TNC, divided the land into areas of low, moderate and high relief and overlaid a green tint on the terrain colours to depict relatively flat areas. Regions with unreliable or incomplete relief information were shown devoid of tints. The heights at which the chart depicted changes from low to moderate to high relief were not necessarily the same on adjacent sheets, nor constant for the whole sheet (Harvatt[14]).

4. Other Scales

Aeronautical charts at scales smaller than 1:1,000,000 are produced for plotting purposes, such as the Global Navigation and Plotting Chart (GNC) and in support of high altitude, long range, radar rather than visual requirements such as the 1:2,000,000 Jet Navigation Chart (JN) for B-57 and B-58 aircraft, and the 1:2,250,000 Admiralty Air Chart (AAC) used for maritime reconnaissance.

The production of mapping at scales larger than 1:250,000 is a national responsibility. 1:50,000 scale land mapping is used extensively in helicopter and fixed wing tactical operations and both the US and UK production agencies have research programmes aimed at improving their suitability in flight. A pylons and obstruction overprint, for instance, has recently been added to the UK 1:50,000 series. There are no international agreements on sheet lines, content and coding, although 1:50,000 has been agreed as the NATO standard scale. When available, 1:100,000 and 1:25,000 mapping also may be used in helicopter operations; the US Army Map Service Pictomap series at 1:25,000 scale, a photomap product is one example.

It is evident that the range of aircraft operations in which a given map is used depends on its information content and scale, and that at scales smaller than 1:250,000 the number of different operations is comparatively small. Yet within any single class of aircraft operation, whether VFR or IFR, low or high altitude, low or high speed, or strategic, tactical or civilian operation, the variety of uses of a given map series is large. Maps are rarely tailored for specific aircraft systems. Most are used in a variety of different aircraft, with different crew constitutions, different cockpit layouts, different vibration characteristics, different lighting systems, and different avionics, navigation aids and sensors. The same map is likely to be presented to aircrew hand-held, in a roller-map display or in a projected map display, and it may be viewed in a north-up or track-up orientation. Distinctions are not made between maps for day and night operations, nor are different series produced for training and operational purposes. Peace time and war stocks may differ in air information overprints but they are otherwise identical.

Under certain circumstances the same map, or similar maps differing primarily in terms of scale and sheet size, may be used for mission briefing, pre-flight planning, in-flight orientation and re-orientation, and de-briefing. At the most fundamental level of analysis, distinctions can be drawn between map reading in these phases in terms of visual and cognitive tasks. Christner and Ray[103] suggested that search, recognition and memory are the main task components involved in map reading. Phillips et al.[267] distinguished absolute and relative estimation of height and visualisation in a cluster analysis of relief interpretation tasks. Morgan et al.[74] suggested that information displays in general could be analysed in terms of the contribution of individual display functions. These are listed below, with examples drawn from map reading in aircraft navigation:–

(1) Quantitative reading – Reading spot heights
– Reading grid references
– Measuring distances
– Reading compass bearings
– Reading time-to-go on planned route.

(2) Qualitative reading – Judging approximate distances
– Estimating true position right or left of planned track
– Interpreting terrain slope, up or down
– Estimating line-of-sight and above or below radar horizon.

(3) Check reading – Checking integrity of navigation system by comparing indicated with known position
– Checking completeness and accuracy of map with intelligence information, visual contact from the air.

(4) Setting – Setting co-ordinates of way points and destination in a map display
– Slewing a map display.

(5) Tracking – Scanning a route or linear map feature
– Maintaining desired heading indicated on a map display.

(6) Spatial orientation – Maintenance or recovering geographic orientation
– Correlating map information with ground information
– Maintaining awareness of compass directions
– Route familiarisation
– Indicating location of destination, checkpoint features, beacons etc.

It is possible to think of other map reading tasks that do not readily fit into these six categories, such as matching verbal descriptions of ground information with maps during Forward Air Control (FAC) operations, plotting routes and annotating maps with route-plan and tactical information and searching maps for features, checkpoints and hazards. Nevertheless, the fact that all of the functions listed by Morgan et al.[74] are involved in reading aeronautical charts is indicative of the complexity of map design problems.

Analyses of the aviator's map reading tasks during different phases of aircraft operations may identify requirements that are incompatible or inadequately met. But further sub-divisions of map functions and arguments for more specialised mapping must be weighed against the economic, production and logistic consequences of map proliferation.

4c ANTICIPATING FUTURE OPERATIONAL REQUIREMENTS

The methods currently used for establishing operational requirements for aviation cartography have been discussed above in Section 4a. Because map production is so time consuming there is a long period of realisation before a new product can be made available to the user. Thus, it is axiomatic that operational requirements analyses should be anticipatory and forward looking: the continued validity and flexibility of current analytical procedures will be critical determinants of the quality of cartographic support for future aircraft navigation and guidance systems.

It can be argued that the full potential of many current navigation and guidance systems has not yet been fulfilled or has been delayed. For example, suitable mapping was not prepared concurrently with projected moving map displays, maps for low level operations and night flying have not kept pace with operational needs, and the technical feasibility of sensor-map comparison (e.g. radar) has not been matched by appropriate cartographic developments. It is evident, for instance, that the sort of effort devoted to the development of infra-red line scan or sideways looking radar sensors has not been accompanied by adequate consideration of the cartographic aids that are required before, during and after reconnaissance missions. In this context, the implications may go beyond the traditional bounds of cartography, to surveying and aerial photography, to provide material more appropriate than traditional maps for aiding navigation in the future, when much of the information provided by sensors may not be depicted on existing maps, and when much of the cartographic information provided is irrelevant or redundant, and may clutter or obscure the limited information that is relevant. The problem does not end if a suitable form of cartographic material tailored for a particular operational role can be proved and developed. Proficiency will depend on the identification of necessary skills in interpreting the material, and on these skills being acquired by prospective users.

The difficulty in anticipating future operational requirements and providing adequate cartographic support for them in time is not generally that problems are insuperable or that cartography must always lag behind. The major problems and their implications can be deduced from a comprehensive statement of the requirement. Knowledge of the operational roles, of the associated technology and of the human factors problems to be overcome is also available or can be deduced. The human factors procedures to be followed in evaluation can be derived and stated; and also the criteria which cannot be compromised. But there is no point in waiting until a new system is well advanced towards coming into service before beginning the extensive programme of cartographic and human factors evaluation and testing necessary to establish the operational feasibility of the requirement, to verify that the aims are attainable and to quantify the efficiency of the system in service. More support earlier is needed, planned systematically and with care, linked to professional cartographic production expertise, and with a total effort matched to the time scale within which the experimental programme of map production, testing, evaluation, modification and checking must be completed. In no single instance in the past has the right kind and amount of cartographic and human factors support been applied to an operational requirement at the optimum pace during its evolution. Only recently have the prospects improved for providing answers for operational planners in time, based on proper evaluations using professionally produced experimental cartographic material.

The cartographic requirements of projected map displays (PMDs) illustrate some of the problems of anticipating operational requirements for cartographic support. In papers describing the development of prototype projected map displays, Honick[366,367,119]) commented on the unsuitability of conventional topographical maps for this application and noted that trends in cartography at the time were retrograde as far as PMD legibility was concerned. In one paper, (Honick[119]) he is quoted as saying:–

> "..... there appears to be no indication that the lessons of human engineering on the legibility of type, the importance of contrast and the virtues of colour as an information medium are being exploited in their application to cartography."

These feelings were echoed in other papers at the time concerning the special cartographic requirements of projected map displays e.g. Anderson[368], Boot[167]. Murlin[369] and Roscoe[166] advocated negative format, white-on-black maps to minimise the display brightness at night; Roscoe[166] also called for PMD map changes in content, symbology, scale, print size, contrast and colour. The cartographic community, on the other hand, have been far less optimistic about overcoming the economic and production difficulties of special purpose PMD maps. Representing this point-of-view, Campbell[370] stated that standard map series must be used as the alternative was too complex, costly and time-consuming. This attitude has prevailed. Currently PMDs are fitted with standard topographical maps and attempt to overcome legibility problems by overmagnification and high-contrast copying (McGrath[160]; Taylor[338]). In an extensive analysis of PMD design requirements, Carel et al.[196] have assumed that standard mapping will continue to be used in the future. They argue that future displays should be designed to ensure that conventional maps are legible by improved resolution, better optics, and high-image contrasts. Whereas this conclusion seems a logical deduction from past experience, it may underestimate the flexibility of cartographic production methods and the effects of future technical developments. A programme of research in the UK on the design of PMD maps has demonstrated that simple, effective modifications to standard mapping can be made for PMD purposes with comparatively little cost in cartographic effort. (Barrett et al[345]; Taylor[338,100,371]).

A major trend in operational requirements, identified by Misulia, is the users' need for more specialised, timely and up-to-date information. In the past, he argued, map producers had no alternative but to furnish general-purpose information because the manual procedures and materials involved prevented a quick response. This was tolerated because the response times required by the user and the operational systems were not so demanding. Operational systems have increased in complexity, requirements have diversified, and response-times have become slower. Partly in parallel and partly in anticipation of the changed requirements, developments in the automation of various cartographic functions and advances in allied disciplines have speeded-up production methods and provided greater flexibility in the format in which the information can be presented.

Steakley[373] identified two main technological advances in aircraft navigation and guidance relevant to future cartographic requirements that have arisen in response to increased aircraft performance. Firstly, the introduction of airborne digital computers will relieve aircrew of many of the "mechanical" aspects of navigation; aircrew will be required to monitor instruments and displays and exercise veto power, overriding a sensor or changing the flight plan. Airborne computers will be used to integrate vast amounts of information from a variety of sources, and display the information in a useable form. Secondly, technological advances in sensors will be characterised by improved resolution and reliability. Inertial navigation systems, forward and side-looking radars, doppler radars, image-intensifiers, and forward looking infrared (FLIR) are prime examples.

The consequences for cartography of these developments in operational systems are numerous. An accumulation of topographic and cultural data will be necessary to support these systems. Inertial navigation (IN) systems will require cartographic definition of new great circle airways, and the production of great circle overlays for air traffic purposes. In updating IN systems, ground fix positions will be needed, based on a common geodetic reference system, and the system must include knowledge of geographical factors until completely drift-free gyroscopes become available.

The provision of radars with higher resolution and greater sensitivity control will allow the pilot to locate fine detail in areas of minimum topographical and cultural data whereas in mountainous areas the gain can be adjusted to display larger patterns. Radar predictions will be necessary to utilise radar potential fully. Ideally, these predictions should be derived from a digital cartographical base. Thus, by appropriate programming and logic, predictions could be made available for specific routes at short notice. The Digital Radar Land Mass simulation (DRLMS) programme has arisen from the development of this concept.

Doppler radar combined with radar altimetry will make it possible to measure aircraft altitudes with exact spacing, accumulate topographic profile recordings and make comparisons with information stored in the aircrafts' computer (terrain contour matching). The correlation could be used to update an inertial navigation system and remove drift errors. The guidance system for the cruise missile uses the principle of terrain contour matching for updating IN system errors.

In general, these developments tend to emphasise machine-map reading requirements rather than man-map reading. However, it would be incorrect to assume that map information will not be displayed in the cockpits of advanced manned aircraft systems. Man's value as a secondary navigation computer and map-sensor comparator will not easily be replaced. As long as man's executive role is valued, map content and coding will continue to be important in human factors issues,

although it is likely that the medium for display will often be different from the paper format used at present, such as computer generated map displays, plasma panel displays, laser-hologram displays, colour video displays, combined CRT/ map displays and, of course, projected map displays.

CHAPTER 5

ADAPTING MAPS TO THE COCKPIT ENVIRONMENT

Maps are employed in many different environments including the cartographic drawing office, the flight-planning room and the aircraft cockpit. Problems arising when working with maps in these environments can be overcome by changing the map, the working environment or both. The aircraft cockpit is probably the most critical environment, and yet the least flexible of these three.

Problems related to the use of maps in flight tend to be solved by adapting the map to the cockpit in flight planning or in map production. For instance, maps may be cut into strips, joined, folded or mounted in booklets during flight planning to make them easier to handle in the cockpit environment. Before this, as part of map design, the sheet size has been chosen to minimise the number of pieces of map that need to be joined in flight planning. Also, symbol codings are selected to maintain legibility under cockpit environment conditions, such as vibration, dim lighting and, perhaps, red illumination.

Map production and flight-planning environments are designed to make working with maps easier, for example by the choice of lighting and work surface. Until the introduction of automatic map displays, there was comparatively little evidence of in-flight working environments being adapted to facilitate map reading tasks. Navigator and plotting stations in multi-crew aircraft may take into account workspace factors such as anthropometrics, console layout, work surface and seat design, illumination and optimum viewing angles. But in single-seat and dual-seat aircraft, changes in the working environment to facilitate map reading have been few in number and minor in nature, such as the provision of map pockets and knee-boards. This is largely because of the low priority given to map tasks in the original system design. It is also due to the high flexibility and adaptability of both the paper map and the map-user, and the comparative inflexibility of existing cockpit workspaces.

5a WORKSPACE

Cockpit workspaces are crammed with displays and controls, limited in room, and often noisy and vibrating. Dependent on role and aircraft type, aircrew may at one extreme have ample time to select a map for occasional consultation, or at the other extreme may refer to it constantly for vital information on which their safety depends. Conventional topographical maps on large sheets, with the legend perhaps remote from the part of the sheet being consulted, are cumbersome and impractical to handle during flight. Continuous navigation and target identification are among the tasks requiring the map to be used in various ways, and it may be necessary to write on it, to fold it, to transfer to the correct part of another sheet, to orientate it track up or north up, or to interpret it with reference to other material. Aircrew may be handicapped in map usage by special equipment, such as masks, goggles or gloves, by the vibrating environment in which small detail on a map becomes unreadable, or by poor illumination which may be dim or red or both.

Conventional hand-held paper maps are adapted to this workspace by the pilot, in his pre-flight preparation and in his handling of the map in flight. The ability of the pilot to adapt the map to his own particular needs is one of the unique features of paper as an information display medium. But there are limitations on what can be achieved by relying on the flexibility of the paper map and its user. These became apparent when aircraft began to fly lower and faster, when systems became more complex and when the pilot's task became more demanding. The need arose to unburden the pilot, by performing automatically some of his more routine functions, such as navigation computing. This, it was argued, would release more time for the pilot to carry out his primary roles of monitoring the system state and decision making (Bond[374]). Maps began to be displayed automatically, initially in direct-view roller map displays, and later in optically projected and electronic map displays. This logical development meant that the task of adapting the map to the cockpit environment became the responsibility of the engineer rather than the pilot. Thus, maps became a part of the pilot's workspace, and they had to be fitted to the workspace in the same way as other aircraft instruments such as altimeters and compasses.

Physical Size of Display

One major constraint on map displays is that space within the aircraft itself and behind the display panels is limited. There are severe penalties for weighty and bulky equipment and for aids with large power or cooling requirements. Map displays must therefore be compact, light in weight, accessible and easy to maintain, and capable of installation within the strict aerodynamic confines of modern high performance aircraft. Map displays have to be positioned so that they

do not interfere seriously with normal access to and egress from the cockpit and could not constitute a safety hazard in the event of emergency use of an ejector seat. In addition they must not hamper the use or sensitivity of any other hand or foot controls. Minimum size is more contingent upon the psychophysiological factors such as the resolving power of the eye, and the ability of the pilot to operate the controls for the map display. In high-performance aircraft, escape clearance is a major concern and consequently the display size has to be kept small. "Slide-out", "pull-down" or "fold-up" methods of storing displays increase the number of locations in which a large map display may be placed when not in use. But ejection clearances mean that these techniques are only viable for aircrew stations without ejection seats.

Location

The primary considerations in determining the location of a map display in the cockpit are as follows:–

(1) It must be usable by more than one aircrew member concurrently if operational requirements imply this need.

(2) It must not interfere with any other tasks, or with the pilot's or navigator's view of other displayed information.

(3) It must not lead to confusion by being mistakable for any other information because of its design, appearance or location in the cockpit.

(4) Its assigned position in the cockpit should reflect the priority of navigation information to aircrew.

(5) It should be chosen to minimise eye movements between the map display, other related instruments, e.g. compass, and the outside world.

Navigation information would lose much of its significance if it prevented the pilot from seeing correctly his height, speed, heading, and rates of climb, descent, turn or acceleration, but it is equally true that much of the information about the state of his aircraft, and even its assurance of his safety, can become almost valueless if he is totally lost. Navigation information must therefore be assigned a prominent place in the pilot's or navigator's workspace in accordance with its importance for the operator's task. Different operational roles may attach different priorities for map information and hence there may be differences in the optimum positioning of the map display.

Eddowes[375] provided a series of drawings of cockpit layouts which reflected the subsidiary role assigned in the past to navigation aids in the cockpit, and suggested a reappraisal of the relative importance of navigation information which led to a repositioning of map displays nearer the top centre of instrument panels. He argued that the need to carry out almost continuous scanning and re-accommodation between the display and the terrain meant that head-down positions, low in the cockpit, should be rejected. De-centred positions might lead to variations in the visual accessibility of the display during turning manoeuvres. This might then cause a preference for right or left-handed approach turns; during attacking manoeuvres such preferences might be detected by the enemy, with undesirable results. Lewis and de la Riviere[360] installed a roller map display in a top centre position and recorded 23.5% head-down map reading time compared with 28.4% for hand-held maps. The roller map display also produced a marked decrease in radial head movements during map reading. In practice, map displays are usually installed in low centre, head-down positions, particularly in strike and ground support aircraft such as the Harrier and Jaguar, where the top centre position is normally occupied by a collimated Head Up Display (HUD) showing nav-attack data, attitude, speed and attitude information.

Eddowes[375] anticipated this argument with respect to high priority rival displays, such as a primary attitude display and an intercept radar, and added that his line of reasoning could lead to the adoption of more display location sharing in the cockpit. This concept enhances the utility and efficiency of employment of limited display space at the cost of potential multiple unserviceability from a single malfunction and at the cost of requiring that the function of each space at any one time must be totally clear and unambiguous in its presentation since the same space may be occupied by different displays at different times. Multi-function combined map displays have since been developed, but none have been installed in what could be described as truly a "head-up" position, (Webb[376]; Dure[377]; Suvada[378]; Braid[344]; AGARD[379]). Furthermore, collimated HUDs or Helmet Mounted Displays (HMDs) are unlikely to be used for displaying map information in the future because of the serious difficulty of obtaining adequate contrasts for map detail superimposed on the out-of-cockpit visual scene.

Viewing Distances

Viewing distances during map reading affect the visual angles subtended by the map symbols at the eye, and hence affect the legibility of the displayed information. Viewing distances for conventional topographical maps are variable if hand-held, ranging from the near position of visual comfort for reading fine detail, about 6 inches, to the full extent of the pilot's arm, about 24 inches. But generally, the map will tend to be held at about 12 to 18 inches from the eyes. Although no rigid guidelines are laid down for the map designers, inspection of most map symbols suggests that 12 to 18 inches is probably the viewing distance that has been assumed by most of them to be the standard.

In single-seat aircraft, particularly at night when the pilot may need to hold a torch to read his map, most aircrew rest the map on their laps or clip it to a knee-board. The distance between eye position in a tilted head and the thigh when seated is not normally included in anthropometric surveys. An exaggerated estimate can be obtained from data

on the level eye position to thigh distance; DOD Military Standard 1472A gives a 5th percentile of 24.4 inches and a 95th percentile of 26.5 inches for USAF personnel seated body dimensions. Equivalent data for RAF aircrew are 24.92 inches (632.9 mm) and 27.36 inches (754.8 mm) respectively (Bolton et al.[380]). These measurements clearly exceed normal hand-held viewing distances. If maps are needed that are legible without having to be picked-up off the lap and held closer to the eyes, 26.5 inches rather than 18 inches should be taken as the minimum legibility requirement. Few map specifications meet this standard of legibility.

Most panel-mounted map displays are viewed at about 30 inches from a restfained position (Carel et al.[196]). To counter this, recent projected map displays magnify the conventional map image by linear factors as large as 1.63, with a limited optical scale change facility to view larger or smaller areas (McGrath[160]). Magnification is not possible with roller map displays and long viewing distances can cause serious problems. Bringing the map display nearer to the pilot by allowing it to protrude from the panel has the disadvantage of increasing the frequency in changes of visual accommodation that will be required to scan the map display and other panel mounted instruments. Ideally the viewing distance should be about the same as for the pilots' other within-cockpit visual tasks.

Viewing Angle

Human engineering design principles state that the plane in which the display lies should be perpendicular to the line of sight if possible. Lateral and vertical lines of sight should never be more than 45 degrees from the perpendicular. Legibility remains essentially unchanged for lateral and vertical viewing angles between 90 degrees (i.e. straight ahead) and 60 degrees (i.e. 30 degrees off the perpendicular line of sight). Viewing the display off-axis foreshortens the map image and reduces the apparent image size. This can degrade legibility at severe angles greater than 45 degrees off the perpendicular line of sight. As map displays are frequently used they should be located within a ±30 degree viewing angle (Carel et al.[196]).

Bond[374] stated that the plane of the display should "suggest" the plane of the terrain surface. Hence, he argued it should be positioned in the pilot's lap or at the base of the instrument panel. If in the pilot's lap he recommended that it should be tilted at 30 degrees or less to the horizontal. If at the base of the instrument panel, he suggested that it should be tilted between 45 and 60 degrees from the horizontal.

At a given viewing angle, the visual angle occupied by the display is affected by its size and viewing distance. Enoch[205] investigated natural search frequencies during a map reading task and found that coverage of the display was not uniform. Greatest attention was paid to the centre of the display. Search behaviour remained essentially the same for displays subtending a visual angle greater than 9 degrees. As the visual angle decreased from 9 degrees, the direction of fixations increased, interfixation distances decreased, concentration of attention at the centre increased and efficiency increased, measured by the number of fixations falling outside the display area. These results suggest that a visual angle of about 9 degrees may be relatively optimum for map displays in terms of the efficiency of eye-fixation patterns. At 30 inches viewing distances this indicates that a display diameter of about 5 inches is probably optimum.

Functional Reach

Map displays require inputs and settings to be made by the operator while seated in a restrained position in the cockpit. Therefore the location of the map display controls must take into account anthropometric data, such as functional reach. Functional reach refers to the distance from the back rest of an upright operator's seat to the operator's finger-tips with his arm extended horizontally and forefinger and thumb opposed, as if operating a switch. DOD Military Standard 1472A gives a 5th percentile of 29.1 inches (739 mm) and a 95th percentile of 34.3 inches (870 mm) for USAF aircrew. Bolton et al.[380] give a 5th percentile of 29.31 inches (745 mm) and a 95th percentile of 33.83 inches (859 mm) for RAF aircrew. The optimum location will depend on several factors, including:—

(1) The precise nature of the control, e.g. switch, knob, button, roll-ball, joystick.

(2) The angle of the back-rest or seat-tilt, whether upright, semi-supine, or supine, which affects both forward and vertical positioning.

(3) The position of the operator's elbows, which may be in:—

- (a) The near low position, i.e. next to the body with the forearm horizontal.
- (b) The near high position, i.e. next to the body with the forearm flexed upward about the elbow at 15 degrees.
- (c) The far high position, i.e. with the arm extended horizontally from the shoulder.
- or (d) The far low position, i.e. with the arm extended and lowered until the hand is at the level of the elbow when in the near low position.

Morgan et al.[74] give data on the recommended optimum manual areas for these arm positions with the backrest tilted from the upright position back to 60 degrees.

5b HANDLING AND STOWAGE

From the earliest usage of maps during flight they have proved difficult to handle in the cockpit (Ristow[3]), and inadequate provision has been made for stowage and handling. A recurrent theme in earlier experimental evaluation was that existing charts were too large and cumbersome (Kishler, Waters and Orlanski[20]). Wulfeck et al.[101] noted that "the task of navigation is extremely difficult simply because so many charts must be carried, stowed, and handled on each flight. Their large size makes handling very awkward".

Ryder[381] concluded from a review of navigation documents for pilots that a gradual evolution had included additions and modifications to documents, with little reference to the whole system or to how it could best be organised. Bowen and Gradijan[382] commented on the paradox that emergency charts could not be consulted in emergency because they were carried in unwieldy manuals. Watkins'[383] listings provide an indication of the sheer quantity of navigational and other information which pilots of modern aircraft are often expected to carry. The range of paperwork carried on the flight deck was classified broadly by Adderley[384] as follows:–

(1) Flight Manuals
(2) Operations Manuals
(3) Crew Manuals
(4) Maintenance Manuals
(5) Load and Balance Manuals
(6) Flight Plans/Logs
(7) Flight Guides and Radio Navigation Charts
(8) Topographical Maps
(9) Orders and Notices
(10) Aeronautical Information briefing data
(11) Meteorological briefing data
(12) Certificates and Licences
(13) Technical and Maintenance Logs

The interrelations among these classes of documentation when they are in use are complex. The above listing indicates the inherent magnitude of the handling and stowage problems in the cockpit, and provides a perspective for treating maps as a small, albeit important, part of the total cockpit documentation.

The difficulty of handling maps in the cockpit is often associated with recommendations for a reduction in their scale or printing on both sides of the paper, to enable more compact maps to be used or to reduce the number required and the problems in changing map sheets. Ideally from a handling point of view, one map sheet should suffice for the entire route, but this is seldom an attainable objective. Even if it were possible by manipulation of scale and sheet size, it would not necessarily be the best solution. Many maps would have to have less information than the mission required, simply because the necessary information could not be portrayed at the selected scale without causing serious clutter and legibility problems.

Instrument Flight Rules (IFR) operation confined to airways can usually be catered for by mapping the en route phase on a single small scale sheet. Separate charts are necessary for take-off, terminal areas, approach and landing etc. Visual Flight Rules (VFR) operations avoid airways and follow the most convenient route to the destination. Sheet lines for VFR mapping may take into account the most likely routes such as ensuring that clusters of major military airfields are portrayed if possible on the same sheet. Generally, in VFR operations the map user must adapt the map to his en route, or handling requirements by folding the sheet(s), by cutting and aligning adjacent sheets in strips, or by paging and mounting adjacent areas in books or folders.

Military helicopter tactical flying (low altitude, low speed) and some general aviation requirements involve flights on irregular routes within a general area. In such circumstances the same map or group of maps may be used more or less continuously, and it is both impractical and unnecessary to use new maps on each flight. Sets of maps can therefore be cut to size and joined together by pasting with glue to cover the relevant area on one integrated sheet. Semi-permanent tactical information may often be added to the composite sheet after joining, and the annotated product is then covered with a transparent, plastic coating to increase its durability and to facilitate annotation and removal of non-permanent route plan information (Barnard et al.[129]). Elaborate methods of folding tactical maps are taught, but rarely remembered because of their complexity (Harter[352]). Basically, they allow adjacent areas to be unfolded and folded-back in flight with comparative ease, whilst maintaining the unfolded area in a manageable size.

Maps for low altitude, high speed tactical military operations are cut and pasted together in strips to cover the specific route to be flown. Here, the method of folding is comparatively simple because the requirement is for linear rather than area coverage. Target areas need to be mapped in greater detail and with greater accuracy than the en route phase and several 1:50,000 scale sheets may need to be joined together to give adequate coverage of the target area. Plastic map coatings applied by the aircrew may be used for missions that need to be repeated, or simply to make the map more durable on a single flight. Inevitably, there is a high degree of wastage in discarded paper as the main objective is to carry the minimum amount of paper for a particular mission.

Navigators in long-range, strategic aircraft allocated to specific targets have more time to plan and prepare their maps compared with pilots of single-seat tactical aircraft. They also have more time and space to handle maps in flight. Here, topographical maps are often gathered together and indexed in folders or books, individually covered in plastic and annotated with predetermined route-plan and intelligence information. The major problem in this role is keeping the maps up-to-date with new and changing information.

The three methods of handling maps described above – folding sheets, cutting into strips, paging in booklets – cover the broad range of techniques that can be used to overcome cockpit handling problems. It is apparent that when any of these techniques are used, the size of the original map sheet is irrelevant to the cockpit handling problem. For a given scale of mapping the same amount of paper will have to be carried irrespective of the original sheet size. Sheet size and, more importantly, sheet lines, are most relevant to flight planning. They determine the number of individual sheets that need to be joined and the paper wastage and they affect the time spent in preparing map coverage of a specific route. Consequently, flight planning factors rather than cockpit handling tend to be the major determinants of sheet sizes and sheet lines.

A major factor affecting flight planning preparation is whether the maps are distributed folded or flat. Unless the sheet is likely to be kept intact and carried folded into the cockpit there is little to be gained from folding maps prior to distribution. The three methods of handling maps described above are best served by maps that are distributed flat to user. Many topographical maps are folded prior to distribution at considerable expense, presumably to facilitate distribution, but with little or no justification as far as the end-user (the pilot) is concerned. If the maps are distributed flat, it is essential that they should fit into the cabinets used for storing them in flight planning rooms. The sheet size adopted by the UK Ordnance Survey 1:50,000 Series was larger than the previous One Inch Series and too large for standard map cabinets. This caused untold storage problems which could only be solved by buying at great expense new larger cabinets.

Sheet sizes should also take into account the size of the work surface provided in flight-planning rooms for preparing and cutting maps. One simple means of reducing sheet sizes and bulk would be to print superfluous legend and border information on the reverse side of map sheets or omit the legend entirely and publish it separately in a user manual. Legends and all the other border information that surround topographical maps are not required in flight and are cut away and discarded in map preparation. On the other hand, certain border information must be printed with each sheet, for identification purposes, such as its title, sheet number and revision date.

The ability to match and join adjacent map sheets is an important flight planning requirement. Bleeding edges, where topographical information is printed up to the edge of the map sheet, and areas of overlap between adjacent sheets are essential for maps that have to be joined in strips or composite sheets. Adhesive edges requiring moistening or removing of protective strip would also facilitate this process, but the extra bulk caused by the increased edge thickness might lead to storage problems.

Difficulty in obtaining good quality plastic covering is a common user complaint (Bruce[385]; Barnard et al.[129]). Proposals to cover map sheets with plastic covering prior to distribution can be challenged on cost grounds. As large portions of the map are cut away and discarded in flight-planning it is more sensible to cover in flight-planning only those areas that are actually taken into the aircraft. On the other hand, the costs of failing to provide this material are extremely high in terms of increased map turnover, increased time spent in preparation and reduced operational efficiency. The source of the problem seems to be in the procurement and distribution of the material; it could be solved if it were regarded as a cartographic product obtainable as an optional extra when ordering maps through established map procurement and distribution channels.

In many operational roles, the pilot or navigator enters the cockpit with voluminous paperwork, which presents him thereafter with two distinct problems – finding adequate accessible stowage for it, and retrieving easily the particular item which he needs. The form and quantity of maps contribute to these stowage difficulties. Maps of various scales for various purposes may be carried, some of which may seldom be used but which are vital on the rare occasions when they do have to be consulted.

Maps are not usually bound, tagged, annotated or coded to enable them to be readily identified in flight, nor is stowage specifically designed to facilitate their identification and retrieval. Yet it should be relatively simple to devise a scheme whereby maps of different scale or different function could be readily recognised even when folded, and to design stowage which also fulfilled the roles of facilitating such distinctions and imposing a logical ordering or classification of items to assist their retrieval. Such stowage designs should also permit associated items to remain logically associated while stowed. Stowage might be in the form of bins, slots, open or lockable shelving with or without spring clips or similar devices to prevent contents being scattered, damaged or moved in the event of violent manoeuvres. The stowage in the aircraft might simply be devised to hold a standard container which the pilot or navigator was equipped with, and which was itself designed, with compartments tagged, identified and laid out to hold all the various items in a standard logical sequence, so that retrieval could be easily learned, and standard compartment shapes, tags, interleaving and coding could be devised. The stowage must not merely facilitate the finding and retrieval of the required map, but must also assist the pilot or navigator to stow it again quickly and without fuss in its correct slot whenever he has finished with it. More progress has been made in adapting conventional maps for use and stowage in other environments, particularly road maps, than has been made with aviation maps. It is emphasised that in this context in particular, the points

made about maps apply to charts also.

Some organisations produce charts on coloured paper to distinguish them from other publications and to help in stowage and access on the flight deck. Depending on the colour used, the loss of contrast compared with white paper can cause legibility problems for small line detail, particularly under low intensity illumination. The advantages gained in terms of improved sheet identification need to be carefully weighed against the adverse effects of low contrast on legibility. A coding other than colouring the whole sheet may be preferable. Unfortunately, shape or size differences introduce new stowage problems when the flight deck map pockets are designed for a uniform sheet size. Colouring only the edges of the sheet will solve the problem but it involves colour printing and extra costs.

It is important in stowage to distinguish between different scales of map, different functions of maps (topographical, charts, etc) and maps which would be used if the mission went as planned compared with those which would only become necessary in other circumstances, such as using a diversionary airfield, abandoning one mission and being given another urgent one, getting lost, or responding to other unanticipated events or circumstances. The maps themselves, and the way they are stowed, should together provide some effective cross referencing. The form of stowage should incorporate a coding of map type and region.

A problem with tailored cockpit stowage compartments is that, like map cabinets in flight-planning rooms, they become instantly obsolete when the size of the paper changes. Variations in the size of Approach and Landing Charts have caused problems in using map pockets on the flight decks of civil airline aircraft. The solution to this problem lies in standardisation in stowage facilities and sheet sizes, and a better appreciation of the user's requirements by all concerned.

In the longer term, the handling and stowage problem will be alleviated in many types of aircraft by automatic map displays, although much general aviation traffic may continue to rely on conventional maps. With roller map displays, hand-held maps will remain an essential emergency aid in case of equipment failure and in circumstances when the pilot is lost or has strayed, for one reason or another, from his planned route. With projected and electronic map displays hand-held maps must also be carried to show tactical and route plan information for use in emergency when the display breaks down due to mechanical or electrical failure.

Cathode ray tube (CRT) displays are the modern alternative to paper displays of in-flight documentation and navigation data. TV tabular displays, such as used for displaying system management data in the Tornado aircraft, achieve significant reductions in the paperwork that needs to be carried into the aircraft. The main problems in CRT presentation are the limitations of computer memory storage capacity and the difficulty of colour-imaging. These problems are largely overcome in combined projected map – CRT displays, such as the Ferranti COMED (Aspin[386]). Notwithstanding the need for paper maps as a systems back-up, combined displays have tremendous advantages over conventional projected map displays for storing and displaying navigational information. The write-on facility afforded by the CRT can be used to store and display route plan and tactical information, obviating the need for continuous reference to hand-held maps. Sensor information such as FLIR, LLTV and Radar can be displayed separately on the CRT or superimposed on the map image. Dynamic flight information can be displayed on the CRT, such as the production of revisionary primary flight and engine instruments, fuel and stores management and tables of way-point co-ordinates. Furthermore, the increasing film-strip capacity of contemporary displays (57 ft at 35 mm in the COMED) allows a variety of colour coded, non-dynamic, and otherwise printed data to be stored and displayed in addition to topographical information, such as emergency procedures, flight information publications, approach and landing charts, aerodrome plans, and indexes. All this information can be available in-flight by selection of the appropriate display control button.

Routes which are planned ahead lend themselves in principle to mapping in strips or in sequential overlapping pages, whereby cumbersome map sheets are not needed and the problems of folding them can be avoided. Automated cartography may be able in the future to introduce a comparable flexibility in preparing small pages and sequential strips of paper maps to the flexibility now available in producing electronic displays, such as COMED. Appropriate map forms for a variety of operational roles can then be envisaged, including map aids for navigating and following a particular route in general aviation aircraft fitted with few navigational aids. The effectiveness of any aids of that kind depends not merely on their content and the logistics of their production, but also on their presentation and the logistics of their handling.

A major constraint in the past on the uses of maps in flight has been the inability either to adapt them for easy handling within the confined cockpit workspaces or to devise adequate handling methods. Paper is the traditional medium for printed information but it is not necessarily the most suitable in flight. Quite small experimental trials of alternative layouts of pages, of overlapping edges, of sequencing and of cross referencing might produce substantial improvements, particularly if associated with the development of materials such as the mylar products used in Vietnam, suitable for printing without distortion or weakening, that can be folded without stretching, tearing or permanent creasing, and that permit clear annotation, easy removal of annotation and hence, subsequent re-use. Current uses of maps are not solely determined by their content and presentation, but are a function too of their ease of handling.

5c ILLUMINATION

The legibility of maps is a function of both the intensity and the colour of illumination. The intensity of illumination affects the ability of the eye to resolve detail and discriminate brightness contrasts on maps; the colour of illumination determines the appearance of colour coded symbols and may render them illegible under certain combinations of illuminant and printing ink. In aircraft cockpits, maps are read under lighting conditions that vary in intensity from bright sunlight (10^7 milli-lamberts) to artificial lighting close to extinction during exterior darkness (less than 10^{-3} milli-lamberts). Whether illuminated by reflected light in the case of hand-held maps, or transilluminated in projected displays and some forms of roller displays, or self-luminous in electronic displays, maps must be dark enough to be usable in bright sunlight and bright enough to be read at night without being a major source of light within the cockpit. At night, ultra-violet and electroluminescent sources, electrical discharge lamps, and incandescent tungsten and quartz-iodine filament lighting may be employed in aircraft cockpits, each with different spectral distribution characteristics. Furthermore, the effective output from these light sources may be varied by optical filters, by altering the voltage and colour temperature, or by reflections from surfaces within the cockpit with different spectral reflectance properties. Relative spectral energy distributions, luminances, chromaticity co-ordinates and correlated colour temperatures for most radiant energy sources are given in Wyszecki and Stiles[387]. NATO STANAG 3224 states that the chromaticity co-ordinates for red cockpit light should be within the limits:

Y not greater than 0.306 or less than 0.281
Z not greater than 0.001.

Illumination at Night

The rationale behind most cockpit lighting systems is that night flying involves two distinct visual tasks:

(1) External cockpit vision, for detecting and discriminating objects at low levels of illumination using dark adapted, low acuity, para-foveal rod receptors. The importance of external cockpit vision varies in different operational roles, aircraft types and phases of flight.

(2) Internal cockpit vision, for reading instruments and visual displays such as maps, requiring the high visual acuity provided by the cone receptors in the fovea of the retina which operate at comparatively high levels of illumination.

Dark adaptation of the eye results from prolonged periods in the dark. Exposure of the dark adapted eye to bright light reduces the ability to see dimly illuminated objects; the degree of disruption and the subsequent recovery time depend on several factors including the intensity, colour, duration and retinal location of the exposure. (cf; Chapter 3a).

The effect of internal cockpit tasks on external night vision can be reduced if the level of intensity of light within the cockpit is low, if the colour is outside the range of sensitivity of the rod receptors, if the duration is brief and the area of exposure of the retina small and central (foveal). These effects on dark adaptation have been widely demonstrated under laboratory condition, e.g. Hecht and Hsia[388]; Kinney and Connors[389]; AGARD[174]. The important problems are whether or not these effects produce operationally significant savings in night vision sensitivity and whether or not they are detrimental to the performance of within-the-cockpit tasks, such as map reading.

Prior to and during the Second World War, maximising night vision sensitivity was regarded as an essential requirement for night fighter and bombing operations. Consequently, ultra-violet and low-intensity, red-filtered tungsten lighting were used extensively to restrict wavelengths in the interests of dark adaption.

Ultra-violet Lighting

Ultra-violet lighting was used in USAF aircraft from 1940 to 1947 and in Luftwaffe aircraft throughout the Second World War (Jolley and Planet[390]; Kurschner[391]). Ultra-violet radiation between 320 mu and 400 mu transmits very little visible light (it was sometimes called "black light") but produces visible reflections when directed at radioactive or fluorescent paint. The earliest fluorescent paints used for instrument markings emitted a green colour under ultra-violet light. Kurschner[391] reports the brightness of these green markings as 0.3 milli-lamberts. Developments eventually made it possible to produce orange-red colours under ultra-violet lighting which had less effect on dark adaptation than green light.

Although ultra-violet lighting had an operational advantage over other lighting systems in that the phosphorescent markings continued to glow for periods of up to one hour after failure of the electrical system, it also had several serious deficiencies. Visible reflections on the canopy and from other objects in the cockpit such as white cables and bright metal were frequently excessive. The brightness of fluorescent markings was difficult to control. The absence of background illumination resulted in a floating effect for instrument markings, known as the autokinetic illusion. Ultra-violet lighting also causes fluorescence of the crystalline lens in the eye which results in aircrew complaints about a vapour-like veil in the cockpit. Many aircrew reported extreme visual fatigue on long missions.

Opinions on the relative merits of ultra-violet lighting compared with other systems have been divided. While the USAF used ultra-violet lighting during the Second World War for instance, the US Navy used red cockpit lighting.

Kappauf[392], reviewing the literature, reported only one direct comparison of instrument reading under the two kinds of lighting. Craik[393,394] compared white and red floodlighting, ultra-violet lighting and self-luminous paint and found that the ultra-violet illuminated instrument had to be about ten times as bright as when illuminated by white or red light to be equally legible, as measured by speed of reading. Similar difficulties were experienced with self-luminous paint as with ultra-violet lighting: accommodation was not easy and markings seemed to scintillate presumably due to fluorescence of the crystalline lens. Probably as a result of Craik's work, the UK Flying Personnel Research Committee endorsed red lighting as superior to ultra-violet in terms of instrument reading performance and RAF night flying aircraft were subsequently equipped with multiple red, white and ultra-violet lighting systems (Kappauf[392]).

During the period that ultra-violet lighting was widely used some sources, such as Smith[395], described how maps should be printed in fluorescent inks. However, most sources advised red map lighting. Pinson[18] examined the effect of different map illuminants on dark adaptation and map reading. He found that broad map markings were legible at about 0.005 foot lamberts whereas print of "ordinary size" was legible at about 0.05 foot lamberts with contrast at 80% and reading distance 15 to 18 inches. He concluded that map brightnesses of 0.01 to 0.1 foot lamberts were necessary. Colour of illuminant (yellow-green or red) had no apparent effect on legibility when photopic brightness was held constant and red illumination or red fluorescent marking was recommended to help preserve night vision. Following this work, Armstrong[19] reported an investigation of the effect on night visual acuity of viewing all-purpose aeronautical charts designed to be used under daylight or white, red, amber or ultra-violet lighting. Acuity was measured after a 25 minute period of dark adaptation and following 10 second periods of map reading under red and ultra-violet light. Dark adaptation thresholds were raised by only 0.3 log units, a loss which was nearly recovered one minute later. The author concluded that, provided the light intensity was kept to a minimum necessary to read the smallest print, neither illuminant significantly disturbed dark adaptation. No further development of these charts was undertaken after 1943. Crandall[396] reported that fluorescent charts were mass produced in the US for wartime using fluorescent impregnated paper and standard process inks, but no record of their evaluation is available. Since the Second World War the requirement for map legibility under ultra-violet cockpit lighting has diminished. Fluorescent nautical charts have been developed recently at the US Naval Oceanographic Office using new inks and more sophisticated light sources. No aeronautical applications are reported (Crandall[396]).

Red Lighting

The main controversy has concerned the effects of red cockpit lighting on map reading performance. As early as 1923, red lighting was advocated in the UK as the best means of preserving the aviators' night vision (Livingston). Red cockpit lighting was used by the RAF as the primary means for preserving night vision throughout the Second World War. This practice continued through the 1950s, when it was taken up by the USAF, among others. Only since the late 1960s has the requirement for red lighting diminished, to be replaced by low temperature white lighting in the most recent military aircraft.

The serious consequences of an illuminant of restricted chromaticity for colour coded displays and map reading were realised in the UK in the 1930s. RAF topographical maps were modified to meet the requirements of red illumination. Purple hypsometric layer tints with high red light efficiency replaced the conventional browns. Similarly, blue and black were used for overprinting navigation information, and red coding was deliberately used for features not required at night, such as roads. Later quarter inch series (GSGS 3957) and 1:500,000 scale series (GSGS 4072) continued the practice of using purple layer tints into the 1950s.

During this period a considerable amount of human factors research was devoted to the problem of designing maps for greater red light legibility. Some of this early work is reviewed by Wulfeck[398] and Chapanis[39]. The need for special-purpose maps was widely advocated. Hartline[399] reported that 30 seconds of map reading in white light at 0.2 foot lamberts, judged to be the minimum comfortable brightness, caused a rise in threshold to about 10 times the completely dark adapted value. Recovery of full sensitivity took 4 to 5 minutes. On the basis of these results, he recommended that red illumination should be used in conjunction with specially printed maps. The work of Pinson[18] and Armstrong[19], already referred to, supported Hartline's contention, as probably did Pochin and Wright[400] in a paper on coloured light in map reading that is no longer available. Kappauf[392] refers to a 1945 UK Admiralty Research Laboratory report that orange lighting had been chosen for chart reading and that filters with a sharp cut-off near 560 mu were considered ideal as they allowed discrimination of essentially all chart colours except blue while maintaining partial rod dark adaptation. The report also pointed out that exposure time rather than intensity may often be the more critical factor in disturbing night vision.

At the RAF Institute of Aviation Medicine, Whiteside[30] took photometric measurements and made controlled observations from one observer in probably the first systematic study of the legibility of maps under low intensity red lighting. Comparing two charts, the ICAO (Europe) 1:500,000 scale Series, printed with brown layer tinting, and a prototype for the RAF GSGS 4072, printed with purple layers, he concluded that both were unsatisfactory and that a monochromatic map was required with layers in neutral greys, large type (8 point) boxed in white, and a colour format which selectively eliminated features required only by day when viewed under red light. Subsequently, flight trials were carried out on an experimental monochromatic map with mixed results (Ruffell Smith and Whiteside[32]). In a further study, the adverse consequences for daylight legibility were identified, arising from changing the colour of aerodrome symbols from magenta to black (Whiteside and Roden[31]). Whereas black printing ensured red light legibility, the loss of colour contrast resulted in poor search performance under daylight. Electric blue overprinting was

recommended as a compromise solution for red light and daylight requirements.

Like Whiteside, Dunlap Inc. on behalf of the US Office of Naval Research (Koponen, Waters and Orlansky[331]; Murray, Waters and Orlansky[128]; Murray and Waters[27]; Murray[28]) in studies which compared the standard world aeronautical chart with two experimental charts, took the red lighting requirement for granted, and presumed that the maps must be modified to meet the red lighting requirement rather than the lighting requirement modified to meet cartographic need. Koponen, Waters and Orlansky[331] were only concerned with red light legibility. Readability and search tests, followed by a questionnaire, were conducted on two experimental maps (XDA 9 3-1 and KJN 9-3 4th Ed) viewed under red light at 0.05 foot candles. Data needed for night flying were printed on the back of both charts, and the readability tests were confined to this data. Results from ten subjects showed statistically significant differences on speed and accuracy of reading and subjective opinions favouring the Naval chart (XDA 9 3-1). It was concluded that the differences were probably a function of factors such as visual contrast, symbol and type size, colour and form. The whiter base and blue printing on the Naval chart were thought to have influenced the results. Six-point type size was considered to be too small. An extensive programme of USAF research on map design for red illumination began at Tufts College, shortly after the UK investigations. The entire programme is summarised by Crook, Hanson and Weisz (a)[40]. Individual projects are reported by McLaughlin[34], Crook, Hanson and Wulfeck[35] and Crook, Hanson and Weisz (b)[36] and (c)[37].

McLaughlin[34] and subsequent researchers assumed that the C-4 cockpit lamp, fitted to most US aircraft, would be used for map reading. This lamp has a red filter with the following wavelength specification:–

Wavelengths shorter than 620 mu	– transmission 0
Wavelengths 620 – 650 mu	– transmission > 70%
Wavelengths 650 – 670 mu	– transmission < 40%
Wavelengths 670 – 740 mu	– transmission < 60%

This specification restricts the effective light to a range within which the eye can discriminate nothing but red. McLaughlin measured the relative luminosity and equivalent Munsell values of hypsometric tints and overprinting colours on USAF Aeronautical Charts illuminated by the red C-4 cockpit lamp. Assuming that a 0.02 Munsell Value was necessary for a perceptible brightness difference under optimal conditions, he was able to show that the existing hypsometric tints did not give a regular light-dark brightness progression, nor were all adjacent tints discriminable. He argued that a brightness difference of 3.0 Munsell value units between overprinting and background was the minimum necessary for 6 point type to be legible under low level red light. With a difference of 6.0 Munsell Value units as the upper limit, he called the range 3.0–6.0 the "legibility gap". Most overprinting fell in the value range 0.0–3.0. Assuming a minimum legibility gap of 3.0 units, he argued that the highest hypsometric layer could be no darker than 6.0 units to ensure overprint legibility. White map paper was measured at 9.0 value units. This gave a value range of 6.0–9.0 for printing hypsometric layers. McLaughlin recommended 14 Munsell Values within this range, spaced at 0.21 unit intervals for coding 11 hypsometric layers and 3 other area symbols – town infill, water and areas of inadequate relief information. Woods were not shown on the chart under consideration.

Subsequent research at Tufts College followed two broad directions: firstly, to determine experimentally the brightness contrast necessary between a surface tint and overprinting in order to ensure adequate legibility under low level red light; and secondly, to determine the optimum level of various typographic variables for maximum legibility at given contrasts under low levels of illumination below 0.1 foot candle.

Crook, Hanson and Wulfeck[35] presented performance data on a type cross-out task using lower case geographical names with initial capitals. Subjects were required to read a geographical name and then cross out, from a group of scrambled letters, all letters which appeared in the name. Type size was either 6 or 8 point, red illumination levels ranged from 0.014 to 0.129 foot candles, background reflectance was either 0.26, 0.49 or 0.87.

With black ink of 0.049 reflectance, this gave a contrast range of 0.81 to 0.94. Speed and accuracy scores were obtained from 12 subjects. The results showed that the legibility of both type sizes fell at an accelerated rate as both the level of illumination and the contrast were reduced throughout the ranges tested. Under all conditions 6 point type was less legible than 8 point type. The authors suggested that the impairment of performance demonstrated in the experiment should be regarded as the minimum for operational environments where conditions would be less favourable, such as increased clutter, higher reflectance overprinting and non-optimum type face. McLaughlin recommended Munsell values for hypsometric tints and black overprinting spanned the contrast range 0.81 to 0.92 It was concluded that the recommended hypsometric series would impair performance by at least the amount shown in the experiment.

Crook, Hanson and Weisz[36] used the same letter cross-out task to investigate the effects of typographical variables on performance under low intensity illumination. Six point (0.064" high) Gothic type were used varying in letter width, stroke width and letter spacing. Speed and accuracy scores were obtained from 12 subjects under red illumination at 0.086 foot candles and under white light at 13 foot candles. For all the typographical conditions performance was poorer under red illumination than under white illumination. Typographical variables had little effect under white illumination, but differences in performance increased under red illumination. Medium stroke-widths and medium-to-wide letter spacings tended to be optimum. Regular letter width was considerably more legible than condensed.

Crook, Hanson and Weisz[37] used the letter cross-out task to investigate the effects of background reflectance and typographical variables on legibility. The results showed that background reflectance can be reduced to 50% without

serious loss of legibility if type at least as large as 6 point capitals is used with medium stroke width, medium to wide letter spacing and regular letter width. With coloured lettering, the loss of contrast was so great as to make colours other than black and dark blue inadvisable for overprinting, unless the letters are large. They recommended that the densest area on the chart should have a red light reflectance of not less than 50% with overprinting of about 5% reflectance, leaving a "legibility gap" of 45% of the full reflectance scale.

In their comprehensive review of the problems of designing aeronautical charts for legibility under red cockpit lighting Crook, Hanson and Weisz[40] identified the following alternative solutions:–

(1) Elimination of charts. Substituting a navigational form for routine cross-country flight, such as suggested by Cramer, Waters and Orlansky[330,401].

(2) Day and night charts printed on separate sheets.

(3) Day and night charts printed on two sides of the same sheet.

(4) Charts designed primarily for night use.

(5) Charts modified for night lighting without deletions or loss of daylight information.

(6) Modifications as in 5. with elimination of some detail to minimise clutter and obtain space for enlargement of important information.

(7) Colorimetric separation of day and night information, by printing daylight-only information in colours with low red light efficiency.

(8) Combinations of the above alternatives.

In their report, Crook, Hanson and Weisz[40] proposed a map specification which was essentially a combination of alternatives (6) and (7). This called for elimination of a small amount of detail, colour separation of a few additional features, and modification of the remaining features to maximise red light legibility. Two experimental charts were produced, a modified 1:1,000,000 World Aeronautical Chart, and a revised Radio Facility Chart. No objective evaluation is reported. This study was probably the first to point to the serious problems caused by the interaction between low intensity illumination and cluttering. Feature densities that make legibility difficult under good viewing conditions produce serious impairment when the illumination is reduced. Reductions in the information content of conventional daylight topographical maps are an essential component of any design solution to the red light legibility problem. Taylor[402] pointed out that red cockpit lighting imposes two limitations on map reading namely, wavelength restriction and intensity restriction.

(1) Wavelength Restriction. Red cockpit lighting restricts the light to a range within which the eye is able to discriminate no other colour than red. The consequence of this is that the map appears monochromatic and the value of colour coding for search, discrimination and identification of symbols is lost. The appearance of symbols under red light will depend on the precise spectral characteristics of the illuminant, on the spectral reflectance and transparency of the ink, and on the colour of the paper on which it is printed. As a general rule, colours with predominantly long wavelength components (reds, oranges, yellows) tend to appear light under red illumination and lose contrast against a white map background. Colours with predominantly short wavelengths (violets, blues, greens) and large grey/black components (e.g. dark browns) appear dark under red light and retain or increase their contrast against a white map background.

(2) Intensity Restriction. Visual acuity and brightness discrimination are reduced as the intensity of illumination decreases. At brightnesses of less than 0.01 foot lamberts, small print such as 6 point type, can be difficult if not impossible to read. Where contrasts are low, overprinting may be difficult to read and hypsometric tints may become indiscriminable from each other. Reduced intensity interacts with cluttering and crowding to make map reading extremely difficult in areas of dense information.

Since this early research on map design parameters three major world-wide series have been produced which, it is claimed, are legible under red illumination. These series are: the 1:1,000,000 Operational Navigation Chart (ONC), the 1:500,000 Tactical Pilotage Chart (TPC), and the 1:250,000 Joint Operations Graphic (JOG). Red light legibility, such as it is, has been achieved primarily by printing in colours with high red light efficiency and by keeping the background colouring, mainly the hypsometric tints, as light as possible. In effect, the design philosophy for these series follows the fifth solution proposed by Crook, Hanson and Weisz[40], namely modifications without deletions. The US Department of Defence Standard Printing Colour catalogue gives figures on the red light efficiency of different colours in addition to the ink formula, luminosity and chromaticity. Some authors have proposed reverse format black maps as a means of reducing the total light reflected from maps and minimising effects on night vision (e.g. Roscoe[403]). Experimental black maps have been produced mostly at 1:50,000 scale for helicopter operations but evaluations have produced equivocal results (Johnson[404]; Whitworth[405]; Barnard[406]). One of the major problems with reverse formats is in giving adequate representation of relief (Taylor and Hopkin[407]). Currently the primary concerns of human factors research are in assessing the legibility and acceptability of existing "red light legible" charts to aircrew, and in identifying the need for red light legible maps in present day operations.

An experimental study reported by Chisum[408] examined the colour discrimination of selected items on US Coast and Geodetic Survey Charts and USAF Operational Navigation Charts under red and low intensity white light. The

60

study was in three parts. In the first part, paired comparisons of Munsell colour chips were made under both lighting conditions, with the same level of intensity. The colour chips were matched to the colours used on the two charts. Subjects were required to state whether individual colour pairs were the same or different. Results from 70 subjects showed that significantly more errors were made under red illumination. Comparisons involving hypsometric colours and water were most difficult whereas those involving roads and controlled airspace were least difficult. Unfortunately the report does not specify the colours used. In the second part, 24 observers located specific features on the charts under both lighting conditions. Times and errors were recorded. Again, significantly more errors were made under red light but there was no effect on times. Features that were difficult to locate under red light had also been difficult to discriminate as colour chips. But not all of the features whose colours were difficult to discriminate were also difficult to locate on the map. In the last part of the study, 270 aircrew completed a questionnaire. White light was considered by most to be easier for map reading but red light was judged better for night missions when all the duties were considered. Chisum concluded that although colour discrimination was significantly greater under white light, other factors such as shape coding facilitated map reading under red light and the results were more equivocal. She also argued that pre-flight planning helped to offset the decrement in map legibility under red light. Generally, she felt that other requirements, such as dark adaptation and glare were more important than map reading in cockpit lighting deliberations. Brennan[409] supported the view that the colouring of maps was important in flight planning whereas in flight most navigators are able adequately to read maps under red cockpit lighting by relying on cues other than colour coding.

Mercier and Perdriel[410] distributed a questionnaire to 45 military and 118 civilian navigators on preferences for different illuminants for map reading during different phases of flight. Comparisons showed that white lighting was preferred most frequently in cruise conditions, but red illumination was used most frequently during take-off, climb and landing. Younger pilots showed a greater preference for red light. Milligan[411] surveyed USAF pilot opinion on cockpit lighting and found widespread use of white flashlight torches for map reading. This was acknowledged as a common practice in the RAF by McVitie[412].

In 1971, the "red light legible" JOG Series was introduced in the UK and adverse user reaction prompted a comprehensive survey of user opinions (Lakin[340]). Among the many controversial results, the map was frequently criticised as "chromatically monotonous" and many of the most serious criticisms concerned the lack of prominence of important features and the undue emphasis of others. Many of these effects could be directly or indirectly attributed to the constraints on the use of colour coding imposed by the red light legibility requirement. Ironically, only 35% of the respondents described the JOG as readable under red light, whereas 95% said it was legible under white light. But on the other hand, difficulty in reading the JOG under artificial light was not judged to be a serious problem, suggesting that few needed to use red lighting for map reading.

Following Lakin's equivocal results on the need for red light legibility, a major questionnaire survey was undertaken specifically to identify operational requirements for map reading at night (Taylor[348]). Six hundred and seventy-two aircrew responded in a variety of operational roles and only 21% indicated that they used red light for map reading under the most critical night flying conditions. Generally, it was felt that the disadvantages of red map lighting (map reading difficulties) were more serious than those of white map lighting (slightly raised threshold). According to Chi-squared tests aircraft altitude, phase of flight, aircrew age and night flying experience had no effect on map light colour usage: aircraft type and the colour of instrument lighting on current and previous aircraft types had a significant effect at the 0.1 per cent level. Jet aircrew and aircrew who had experience of white instrument lighting used white map lighting most frequently. It was recommended that the red light legibility requirement be removed from topographical map specifications, that a full range of colour coding should be employed, and that methods for improving white map lighting facilities fitted to aircraft should be sought. These recommendations were accepted by the RAF.

NATO medical opinion on map lighting was clearly stated in 1967 in the proceedings of an AGARD conference on aircraft instrument and cockpit lighting by red or white light. (AGARD[174]). The conference drew the following conclusions:–

(1) "There is insufficient evidence to state whether the differences in threshold associated with red or white lighting are significant operationally for this depends on a variable factor, the precise nature of the visual task.

(2) At an experimental level it is generally felt that the disadvantages of red integral lighting (loss of colour coding, accommodation difficulties) outweigh the advantages (slightly lower threshold). White integral lighting – either "low temperature" or lunar – is therefore considered more useful.

(3) If the visual task requires detection of external objects and features and map reading, a small part of the floodlit visual field (sufficient to read the particular part of the map being scrutinised) should be white, as this will tend to prevent loss of dark adaptation in the peripheral parts of the visual field.

(4) The lighting must be variable in intensity according to its users' needs, and aircrew should be taught how to make best use of such a lighting system."

Glare

Glare is normally associated with the general effects of relatively bright light sources, such as visual discomfort, annoyance, interference with vision or eye fatigue. Oldfield[413] describes the effect of bright areas within the observer's

field of vision as similar to a "veiling luminance" or "disabling glare" superimposed on the visual scene. The effect can be accounted for in terms of actual scatter within the eye, neural interaction effects and transient adaptation caused by the observer looking at a bright area before attending to his task. Direct glare and indirect, reflected or specular glare may be experienced when a bright light source is used for map reading in the cockpit. Normally map lighting is shielded or so directed to minimise direct glare. Indirect, reflected glare is more common and is caused by reflections directly from the map and indirectly from the cockpit canopy or instrument glasses. Reflected glare occurs under two circumstances: firstly, when there is a marked difference in the reflectance between adjacent visual areas, as when map reading in a dark cockpit, and secondly, when an area is not perfectly diffusing and concentrates the reflected light in a certain direction, as with maps on glossy paper or covered with a shiny plastic protective coating. The position of the individual with respect to the line of the concentrated glare determines the degree to which his vision will be affected (McCormick[106]).

Maps may be modified to minimise reflected glare by using a reverse format, by a black background, by colouring background areas as in hypsometric tinting, by printing on paper with a diffuse matt surface and by avoiding glossy map coverings. The map can be held in positions that shield other aircrew and other reflective surfaces from light reflected from the map. Most light sources can be adjusted in intensity and shielded to restrict the area illuminated. Increasing the general level of illumination will serve to reduce reflected glare also by reducing the brightness contrast between the map and the surround.

In transilluminated projected map displays, direct glare may arise from sudden changes in the intensity of the display during frame changes when the microfilm passes quickly through the film gate and briefly exposes areas of film that are relatively light. Survey data has shown that specular reflections from the display face cause glare and legibility problems in bright sunlight and to a lesser extent from cockpit lighting at night, depending on the location of the display and the method of shielding employed, if any (Carel et al.[196]). Specular reflection from the display face can be reduced by various anti-reflection coatings. Glare may occur also when the display is adjusted for bright sunlight and ambient light intensity drops suddenly as when flying through storm clouds.

Transilluminated and Self-Luminous Map Displays

Transilluminated roller and projected map displays and self-luminous, cathode ray tube electronic displays have to meet the dual requirements of being bright enough to give sufficient image contrast in sunlight and dark enough to be readable at night without being a major source of light within the cockpit.

Apart from glare, the ambient cockpit illumination provided by instrument and floodlighting at night does not appear to constrain map display design. Dimming is achieved by voltage regulation or by interposing neutral density filters between the light sources and the map image. Carel et al.[196] report questionnaire data on legibility of map displays at night: most displays were regarded as having legibility problems when dimmed to preserve dark adaption although these problems were less severe than those in bright sunlight or with hand-held charts at night. Inadequate contrast, resolution and symbol size featured prominently in the operators' criticisms, but the main problem was one of brightness: if the display is dimmed to a level of intensity that preserves dark adaptation the map becomes illegible. The solution to this problem is unlikely to be found in redesigning displays. It may require cartographic design of special-purpose "night maps", such as reverse format black maps, to reduce the total light flux emitted.

In bright ambient illumination, map displays that light, rather than passively reflect, light as hand-held maps do, suffer from the disadvantage that as the ambient illumination is increased up to 100,000 lux, so the contrasts between symbols and their backgrounds are reduced. Carel et al.[196] reported the open-gate brightness of existing displays as ranging between 200–12,000 foot lamberts with the majority at about 1,000 foot lamberts, which was considered adequate by most users. In the same survey, the authors report widespread criticism among operators that their map displays were not clearly legible in bright sunlight, and that they were not as legible as comparable hand-held, paper maps. Small alphanumerics were most difficult to read, but the survey failed to discover whether the main cause was specular reflections from the display face or the general "washout" contrast reduction effect of bright ambient illumination. Few operators mentioned that inadequate brightness was a serious cause of their legibility problems but the complexity of interacting factors must make it difficult for users to single out subjectively any particular source. In addition to the display luminance, the contrast obtained in the display will depend on the inherent contrasts of the symbols on the original cartography, the contrast on the film in projected map displays, the screen reflectance, and the ambient illumination.

Carel et al.[196] report a series of experiments to identify, among others, the image contrast requirements for projected map displays. Image contrasts ($\frac{L\ max - L\ min}{L\ min}$) ranging from 0.1 to 6.0 and average display scene luminances ranging from 0.1 to 1,000 foot lamberts representing the extremes for most PMDs were compared for alphanumeric and non-alphanumeric symbol legibility under static and vibration conditions, with 2, 4 and 8 line pairs/mm display resolution. Nine subjects took part in the static alphanumeric study, eight subjects in the static non-alphanumeric study, and four subjects in the vibration study. Performance was measured by the amount of magnification the subjects required for threshold and "comfort" legibility. The main effects of luminance and contrast were highly statistically significant ($p < 0.001$) for alphanumeric and non-alphanumeric symbols at threshold and comfort levels of legibility, and they accounted for more than 60% of the variance. There were also significant interactions between luminance and contrast ($p < 0.001$). Generally, visual angle (magnification) requirements increased as luminances and contrasts were reduced throughout the ranges tested. Luminance had a larger effect on legibility than did contrast, and differences between

intermediate and high values had less effect than those between intermediate and low values. Only the combination of low luminance (0.1 foot lamberts) and low contrast (0.1) produced totally unacceptable legibility, and indicated that the minimum contrast for night operations will be approximately 0.5, which is well within practical cartographic limits. At the other end of the display operation extreme, low 0.1 contrast and high 1,000 foot lamberts luminance, the visual angle requirements were well within design limits for map displays. The results are presented in the second volume of the author's report as display design trade-off criteria in a tetragraph of inherent symbol contrast in the original cartography, map display luminance, ambient illumination, display screen surface reflectance, and contrast enhancement filters.

The legibility requirements of combined cathode ray tube and projected map displays (CRPMDs) under high ambient illumination have necessitated optical solutions to the image contrast problem. In the past, CRTs have not been bright enough or persistent enough for viewing under the highest levels of illumination encountered in the cockpit. To make the image independent of ambient illumination, field lens/transfer lens optical systems have been used whereby the two images are formed within the display where they cannot be reached by extraneous light. In order for light to fall on either the map image or the CRT image it must pass through the transfer lens. The image of the transfer lens is the exit pupil for the system, and the diameter of the exit pupil is designed so that it is completely filled by the observers' head, preventing ambient lighting from entering the display (Webb[376]; Taylor[338]; Aspin[386]). A similar field lens system is used in the Ferranti Harrier PMD (Briggs[414]).

Field lens systems have the disadvantage of a limited viewing angle which restricts the observer's head movement and prevents more than one observer from viewing the display at the same time. Moreover, indifferent optics easily result in image-field flatness problems, causing geometric distortion of the map image. Operational experience has shown that a legible map image can be obtained with a bright light source without recourse to a field lens system with all its disadvantages. However, the image contrast requirements for optically combined map-CRT images are more exacting and a field lens system may be the only acceptable solution (Taylor[338]).

The feasibility of all-electronic map displays has only recently come about with the introduction of large capacity airborne digital computers. Brightness problems with raster cathode ray tube displays have been reduced by the development of tubes with 2,000 foot lambert output. In addition to field lens viewing systems, anti-reflective coatings and faceplate filtering techniques using tilted narrow pass band and neutral density filters can also be used to enhance image contrasts. (Hearne[415]; Mann[416]; Oldfield[413]). At present, no electronic map displays are in service, and flying experience with prototype displays is limited (McGrath[160]) to simplified, monochrome formats.

5d VIBRATION AND TURBULENCE

Vibration, defined as vertical motion induced by the aircraft system, is relevant to map reading tasks when it is in the range 1–30 Hz. Below 1 Hz, the amplitudes of motion are large and the whole body follows the motion. Above 30 Hz vibration is likely to be absorbed and attenuated by the buttocks, feet and legs and have little effect on the rest of the body. Within this range, there is some evidence that vibration affects visual acuity. Schmitz and Simons[417], for instance, found that vertical vibrations at 3.5 cps and 2.5 cps affected visual acuity. In still air conditions, little self-induced vibration is experienced in fixed-wing jet aircraft in the range 1–30 Hz. Vibration survey data gathered by Carel et al.[196] for map displays in three aircraft (A-7E, Harrier, Mirage III) showed that for most operators vibration was not judged to have a major effect on map legibility. Vibration is a more serious problem in helicopters, where considerable continuous vertical vibration is caused by the main rotor and varies in frequency and amplitude according to the aircraft's speed.

In an experiment reported by Carel et al.[196], map legibility data were obtained under static and vibrating conditions, using a vibration spectrum typical of a UH-1N Helicopter. Performance effects were measured by the amount of image magnification required for threshold legibility and comfort legibility. Vibration had a significant effect on alphanumeric symbols at the 0.01 level for threshold legibility and at the 0.05 level for comfort legibility. A 42% increase in visual angle was required for threshold legibility under vibration and a 31% increase was required for comfort legibility. Significant interaction effects were found for vibration with contrast/luminance and clutter. A small sample of data for non-alphanumeric symbols showed that the effects of vibration increased as the difficulty of using individual symbols increased under static conditions. Generally, it was concluded that helicopter vibration requires a major increase in symbol size, as much as 50% compared with static conditions or those experienced in fixed-wing jet aircraft. Vibration effects can also be expected to be most severe under conditions of low luminance and low contrast.

Vertical motion induced by atmospheric turbulence can vary from occasional, light to moderate "chop" to continuous severe buffeting experienced at low altitudes, causing large, abrupt changes in aircraft attitude and airspeed. Turbulence tends to be a more severe problem in fixed-wing than in rotary wing aircraft and may make instrument reading difficult and sometimes impossible, particularly in low altitude high speed flight. Survey data gathered by Carel et al.[196] indicated that map displays are difficult to read under buffeting. Generally, it seems that map reading is unlikely to be carried out during turbulence. In severe buffeting, map reading will be prevented because aircraft control requires the pilot's full attention. If the turbulence is of short duration, the pilot will probably wait until the disturbance has passed before continuing to read a map display. If map reading becomes essential in turbulence, for instance when the pilot becomes lost, it is most likely that the pilot will attempt to clear the disturbance by altering altitude. Designing map displays to be legible in turbulence is probably an unnecessary and impractical objective.

5e PLOTTING AIDS

The value of maps during flight may depend on the tools and aids available in the cockpit for use with maps. These may be the traditional navigator's aids: customised rulers, romers, set squares, protractors and dead-reckoning computers. They may take the form of aids on the map itself, such as DECCA overprints, aids compatible with the map surface such as chinagraph pencils and felt-tipped map marking pens, aids built into the workspace such as special map tables, or aids to circumvent some of the degradations in performance associated with the physical flight environment, such as cursors to permit fine positioning under vibrating conditions. Additionally, particular kinds of display, such as projected map displays may both limit the opportunities for using plotting aids and enable novel kinds of aids derived from display technology to be introduced. This may apply in particular with computer generated maps.

A limit on the speed and accuracy with which tasks can be done is set by the aids and environmental conditions, in conjunction with the scale of the map. The aids available and the consequent accuracy in plotting positions and routes may substantially influence the choice of the most appropriate scale for the map. There is no point in choosing a very large map scale for an environment where the severity of vibration prevents accurate plotting.

A tendency is for aids to become progressively more automated, sophisticated and specific to the form of topographical information presented in the cockpit. Bruce[355] described an automatic system for route planning to be used in conjunction with projected map displays, comprising a digitiser, keyboard, computer, plotter and portable data store. For many navigation purposes the pilot, and particularly the navigator, have traditionally been able to assume that they could annotate the map as an aid to route planning and following, to target detection and recognition, and to memory. Where missions have to be planned, specific navigational information must be annotated on the maps either beforehand or during flight; plotting aids must be provided to facilitate this process and should preferably be such that their use does not obscure or interfere with the original content of the map. If a map has to be used to plot linear routes then its range of colours and symbology must be chosen to allow such lines to be plotted on the maps without leading to ambiguity or difficulties in visibility. The detailed form of the map and the purpose of the mission will in part determine whether the annotations have to be in a form which can be removed subsequently or may be permanent since the map will not be used again.

Human factors principles can be applied to optimise the design of tools used for various plotting purposes on maps in flight. Scaling on these aids can be designed to be compatible with that of the map to facilitate the measurement of distance and can be engraved or scribed on the tools in a way which maintains its legibility clearly under the lighting conditions prevailing in the cockpit. Similar principles can be applied to tools designed to measure angle or heading changes. Special symbols may be provided for particular functions. For example a transparent sticker, incorporating a clear symbol and intended to be peeled off the map when no longer needed, may be provided for the designation of points of particular importance during a specified mission, such as waypoints and turning points. The detailed design of these aids may rely on display principles which ensure that they are clearly visible but do not obscure other vital information when they are stuck on. Their relative importance can also be indicated by varying size or colour coding in accordance with the need to draw the user's attention to them. The use of such removable symbols may entail the printing of maps on a material which allows stick-on symbols to be added and removed without leaving a residue or tearing or damaging the map.

Similarly, the ergonomic evidence on the design of controls may be used in providing a method for designating points and routes on the map by means of remotely controlled markers or cursors. Factors to be taken into account include sensitivity of movement required, control-display relationships, the size of incremental steps, appropriate control types, and recommended directions and forces of control movements. All such recommendations would take full account of the physical characteristics of the cockpit environment during flight to ensure that as far as possible the task could still be done under the most extreme conditions liable to be encountered.

Relatively little work has been done on the practical evaluation of map aids for cockpit use. Cramer et al.[330,401] developed and evaluated a navigational form for recording route plan and stores management data for high altitude flight. The suitability of a lighted chart board for day and night use in the cockpit was evaluated by Pride[418]. However, studies on the nature and content of navigation documents (Watkins[383], Ryder[381]) cover their usage in general, rather than the problems of plotting in detail. Whereas training was shown to reduce the errors in direction estimation using tactical maps the effects of various plotting aids and of frequency of grid lines were not covered by Gray et al.[351]. A comparison between one and two pilots navigating in helicopters by Lewis et al.[357] judged their efficiency by the number of designated checkpoints correctly reached, and indicated some advantage for dual teams in reducing initial heading errors. However, errors ascribable to limitations in the accuracy of plotting or in the aids available for this were not covered. The difference between roller map displays relying on paper maps and projected map displays relying on an intermediate photographic process can produce problems in joining adjacent sections of strip maps. Bass et al.[419] were concerned with short term reproduction capabilities for specialised map display strips to meet tactical needs, but the different plotting requirements of roller map displays and projection displays were not considered in detail. The comparative value of the alternative map displays may be as dependent on the efficacy of the associated plotting aids as on the format of the map itself.

The design of grid systems and grid plotting aids is likely to affect the ability of aircrew to plot map positions from co-ordinates and to plot co-ordinates from given map positions.

Two alternative reference systems are provided on most topographical aeronautical charts, the Normal National or Universal Transverse Mercator (UTM) Grid and the Geographic Reference System (GEOREF). The GEOREF or lat/long system which is used most often by aircrew, and by most navigation equipment, divides the map into 15 minute bands of latitude and longitude and the perimeter of each of the resulting quadrangles is pecked at 1 minute intervals. The size of each quadrangle and the ground distance represented by one minute of longitude vary according to the latitude of the mapped area. GEOREFs are normally computed to one minute of accuracy, either by interpolation or with the aid of a ruler. The irregular size of the quadrangles prevents the use of standard transparent graticules or romers. The UTM Grid system is used primarily by ground forces. This system divides the map into 1 or 10 kilometre squares, depending on the scale. These cells are much smaller than the average 15^2 minute quadrangle – but unlike the Georef quadrangle the sides are not always pecked. Peckings may be provided at intervals, such as every 50 kilometres. Grids are normally computed to four figures, requiring interpolation to 1/10th of a grid interval. Romers may be used for accurate plotting, which divide each square into a 10 x 10 matrix. When plotted correctly, four-figure grids are more precise than 1 minute Georefs. The Georef system is printed on virtually all aeronautical charts at scales of 1:250,000 and smaller. The National grid system is printed on large and intermediate scale maps (1:50,000, 1:250,000) which are likely to be used in operations involving liaison with ground forces. Forward Air Controllers, for instance, will tend to use UTM grid co-ordinates when identifying targets on large maps. Conversion from UTM to lat/long is facilitated by printing both grids on some tactical maps. A portable calculator programmed to carry out the conversion has been proposed as an alternative solution (Bruce[385]).

Few experiments have considered the factors effecting position plotting accuracy on maps. McGrath et al.[322] compared the position plotting accuracy of pilots in simulated low altitude high speed flight with the accuracy achieved by independent plotters listening to descriptions of target locations on radio transmissions. The results showed that pilot/plotter teams were as accurate as pilots alone, but the effects of different plotting aids and grid systems were not considered. Romers are unlikely to be used in flight, and are principally a mission planning aid. Guttman and Finley[420] showed that without romers aircrew made errors in four-figure grid references on 12% of the interpolations in each co-ordinate. Additional sources of error can be large, particularly when verbal communication of co-ordinates is involved (Baker[421]). Taylor and Hopkin[151] found evidence for mishearings, confusion errors, number rounding and interpolation errors in an experiment comparing the accuracy of position plotting from six-figure grid references without plotting aids, with the accuracy achieved from verbal descriptions of the location in terms of topographical features. Accuracy to within 200 yards (183 m) was achieved on the majority of trials. Gross errors, defined as over 5,000 yards on the map used, the 1:250,000 JOG, were more likely with grid referencing, and represented 2% of the total errors. Gross errors were probably due to mishearings and confusions. The majority of the remaining errors were less than 1,000 yards and were attributed to number roundings and interpolation effects. Interpolation between large intervals leads to a tendency to over-estimate in the lower half of the scale and to under-estimate in the upper half. The authors concluded that whereas the normal practice of four-figure grid referencing does not represent the limit of interpolation ability with conventional grids at 1:250,000 scale, reliable six-figure grid referencing is unlikely to occur without the use of aids. However, the operational value of more precise grid-referencing is limited by the standard error of chart production at 1:250,000 scale, which Gammon[113] reports as ±275 yards (250 metres).

In general the application of ergonomic principles to map aids seems to be a seriously neglected area, in aviation and elsewhere. This applies to the simplest aids where for example the incremental steps in line thicknesses or symbol sizes may not correspond with just discriminable differences in use, and to more elaborate plotting aids such as the adaption of mechanical or electronic methods for indicating positions on the map, and the choice of appropriate control display relationships and compensating factors to overcome the more serious effects of the physical environment in the cockpit during flight. The extent to which aids could be affixed to various map forms in advance or during flight to aid planning and act as memory aids has not been considered in human factors terms, nor have such aids been defined in a standardised way to meet the various physical environmental constraints, particularly the ambient lighting and vibration conditions encountered in the cockpit. It may well be that the established practices accord well with human factors principles so that considerable improvements could not be attained by a fresh application of those principles. On the other hand it may be that the application of control and display principles to the design and production of plotting aids of all kinds could lead to substantial improvements in efficiency in their practical use.

CHAPTER 6

DESCRIPTIONS OF TASKS USING AVIATION MAPS

6a THE PURPOSE OF TASK DESCRIPTION

The concept of the task description has a particular meaning for those concerned with human behaviour in a working environment, although there is disagreement on what that meaning is. For example, Singleton[422] and Tiffin and McCormack[71] agree that there are confusions surrounding task descriptions and related concepts without agreeing on how they should be resolved. In the present context, task descriptions cover the actions which the man does or should do to achieve a given purpose. The purpose is related to some aspect of his operational role or mission. The task description relates to what he does if it is based on analytical methods applied to his behaviour, and relates to what he should do if it is based on synthesising deductive methods on the behaviour which is necessary to fulfil a particular function. Task descriptions therefore refer to the objectives, to the methods for achieving them, to the workspace in which they have to be achieved, to the equipment and facilities and machines provided, and particularly to the relationship between the man and the machines or tools. In the context of aviation maps, task descriptions cover how maps are used and how much maps could be used for purposes in flight and on the ground in relation to flight, given the environmental constraints of displays, controls, communications facilities and particularly of collateral material intended for use with maps. Task descriptions also imply certain aptitudes, skills, knowledge and experience on the part of those doing the tasks, and this has to be made explicit in relation to particular task descriptions.

Task descriptions may be compiled for several reasons. Most simply the purpose may be to give a factual account of how the task is done. With maps, this can provide a broad indication of which maps are used, how often, under what circumstances. Usage of maps may be expressed as a proportion of the total time, related to the other functions of the man, and related also to the functions which commonly precede and follow map usage. This purpose can be taken to any required level of detail. It may be related to phase of flight, to type of aircraft, to the degree of experience of the pilot or navigator, to the type of mission, to alternative sources of information, to acquired habits, or to constraints imposed by environmental conditions. At a simple level, use of a map may be described in percentage terms but more commonly this is subdivided to give an indication of how the man uses the map. It is important that any form of task description is a passive process, so that the act of obtaining a task description does not itself alter the behaviour it is trying to describe. Descriptions of how the man does the task may be obtained passively by recording his movements, by looking at eye movements, by giving sequential timed descriptions of his actions, by compiling flow diagrams of his action in the order in which he does them, and by noting his extra actions. Descriptions which are confined to his overt activity are not particularly useful or explanatory. Eye movement recordings may indicate that he looked at a particular section of map for a given length of time but will not indicate why he looked at that particular section, what particular symbol he was looking at or what he was looking for; or whether he obtained from the map the information he sought. Further information is therefore needed. This can be obtained by deductions from his actions, by presuming that in order to carry out a particular action he must have gleaned certain information from the map, or it may be obtained by asking him formally or informally questions about his map usage.

A further method, not perhaps as applicable and practical with maps as with certain other information sources, is to change the content of portrayal of information and find out whether the change has any effect on his tasks or on the way he performs them. If there is a measurable difference when certain information is added or removed it is then assumed to be pertinent; if there is no difference it is assumed not to be: but the claimed validity of this process may underestimate man's adaptability.

Such task descriptions, at whatever level of detail they are achieved, provide much needed basic descriptive information of how tasks with maps are performed. The process of compiling systematic task descriptions is often neglected, partly because it involves a great deal of routine and painstaking work, no matter which techniques are adopted. As a result of this neglect there is no sufficient information for many purposes on precisely how maps are currently used. Partly because of this reason aviation cartographers often have only vague ideas on how aircrew use their products. Those who plan new operational roles, new cockpits and new cartographic display aids may also have inadequate information of how maps are actually used. The lack of adequate task description is a general problem, not confined to aviation maps.

Task descriptions may also be compiled to deduce what information is necessary to fulfil a particular operational role. Such descriptions can specify what is required but do not always cover the practicality of the requirement, judged by the financial and technical consequences of providing it. In theory, such deductive methods could lead to new uses for maps or the recasting of traditional uses, although in practice this has seldom occurred. A methodical task description can indicate the problems which have to be resolved in realtion to a new display technique or a new operational

requirement and allow their implications to be gauged. For example in considering tasks involving comparisons between radar and map information, descriptions specifying the kind of information which appears on radar and its directional nature can be used to deduce what kind of information would be needed on the maps and how it should be portrayed to assist pattern matching and adjustment. Task descriptions also reveal the feasibility of proposed operational roles and can sometimes call them into question, by demonstrating that certain information cannot be provided or that certain tasks are beyond human abilities.

Task descriptions are also an aid in specifying selection and training methods. Carter[423] included a job description of the navigator's task in his text on psychological research on navigator training. Task descriptions can be used to deduce the skills required, which should be reflected in selection and training. They can indicate knowledge which is essential and which must be acquired as part of training. They can also indicate the levels of task performance which must be attained if a particular operational need is to be met. It is possible, for example, to deduce required degrees of navigational accuracy for pinpointing targets. It may be possible to take this stage further and deduce probabilities for becoming lost which may be associated with tolerable errors in navigational accuracy. Such information can in turn be used to indicate the scale, the level of detail and the format of appropriate maps which would be most helpful in enabling the tasks to be done.

One problem that arises in compiling task descriptions in most aviation environments is that a single map is used for many tasks and in many ways. Systematic task descriptions may reveal that the range of envisaged tasks is too great for a single map sheet, because it poses insuperable problems of information density, coding or relative prominence. The task description not only indicates what information is needed but also the permissible time in which it must be obtained. The relevant information must not simply be presented on the map but must be presented in a form where it can be found and understood within the time available. If this is impossible, then the task description suggests that the operational requirement cannot in this respect be met by the particular map.

Another profitable aspect of task descriptions is for the person compiling the task description to do the task. This can be one of the most effective and least expensive methods of gaining insight into the nature of the tasks. Numerous objective methods can be used for gathering data about tasks as a basis for compiling tasks descriptions, including tape recordings, films, video tapes and the techniques of time and motion study. From such evidence the fundamental skills and abilities required for a task can often be deduced. However, care must be taken lest the unjustified assumption is made that all that the man does can be accounted for by a simple summation of the contents of the descriptions of his tasks.

It is essential in describing all but the simplest tasks to cover not merely what the man does but what he is responding to, what he is deciding and what he is solving. What he is responding to implies a description of the information available to him. This is relatively easy to state in displays of information which change, such as altimeters or air-speed indicators, but is not at all easy to state when he uses a map. The decisions which he makes can sometimes be deduced from what he does, but on other occasions they have to be identified by questioning him. He may for example examine for a long time information available to him, and decide that the correct action is to do nothing. Problems which he has solved are often reflected in his actions, but it may be necessary to ask him questions in order to discover which factors he has taken into consideration in solving the problems and which he has not, what knowledge and experience he has used and what he has not, what he has remembered and what he has forgotten.

In relation to maps it is usually possible in principle to compile for each task done with a particular map a categorised list of the observed actions and activities, of the deduced and reported further activities, of the length and distribution of the time spent with the map and of the use of the map in relation to other functions. With such a description for each task comparisons across descriptions are possible to show where the same map is being used for very different functions and to indicate in relation to the information displayed which of those functions it is most fitted for. The principle can be extended using task descriptions for other maps to suggest that for certain tasks a different map may be more suitable.

Inevitably, using an analytical approach, the content of the task description is biased somewhat by the methodology adopted. With a synthesised approach relating to envisaged future uses of the map it is more possible to be comprehensive and objective so that the resulting task description is more thorough and less biased. It is also possible to consider more impartially possible extensions of map usage beyond those habitually adopted. In particular, if a broad approach is taken to operational requirements without prejudging whether a map is needed at all or what its scale or content or usage should be, the likelihood is greater of obtaining a task description less constrained by traditional conventional practices. It should not be presumed that such an approach is necessarily better; but in the past the role of maps has been very much constrained by the deficiencies of particular map sheets or environments which users have encountered. There is always a tendency to generalise these deficiencies as applying to all maps under all circumstances, when often they need not do so.

Systematic analyses of navigators' tasks are available. Latham and Spencer[424] recorded the actions of navigators and radar operators during six operational bombing sorties in a study of the effects of fatigue and experience on the navigator's work pattern. Their activity analysis showed that map reading *per se* accounted for approximately 0.5% of the total time on these particular operations, and that experienced navigators spent more time map reading than

inexperienced navigators. More recently, Seifert and Denkscherz[425] and Denkscherz[426] have reported an analytical study of the navigator's task, during the design and development of a new fighter aircraft, where map information is presented on a moving map display.

The early cartographic research literature shows evidence of attempts to obtain descriptions of the map user's tasks. Miller's[11] experimental air navigation map relied on certain task description methods insofar as the principles used in this design were based on actual flying experience and represented the needs of the navigator. Bishop et al.[22] were probably the first to employ task description information, based on interviews and questionnaires, to study operational characteristics of aircraft and identify what is visible on the ground from high altitudes, before preparing a map specification. Task descriptions of alternative comparable procedures should be a prerequisite for drawing up specifications which will meet the needs of the user. Task descriptions in some form are also necessary as a basis for evaluating the adequacy of maps (McGill and Cain[26]), and task descriptions may also be needed to provide a logic for specifying what alternative maps are needed and how they should differ in order to meet the whole range of operational needs (Dorny, Waters and Orlansky[21]). The task descriptions will also provide evidence on the necessary size and handling qualities of maps during flight (Kishler, Waters and Orlansky[20]). These authors recommended a combination of subjective data from users and objective performance tests to develop map specifications, the implication being that information of a task description kind could thereby be derived. Although task descriptions generally indicate that for most spedific purposes the information depicted on many maps is excessive, nevertheless for certain tasks more detailed information may be necessary for adequate task performance (Payne[427]).

Bishop et al.[126] began their attempt to draw up a specification for helicopter maps by conducting a job analysis of the tasks in the helicopter. This raised broader issues as to whether the map should be used as the only aid to navigation and how aerial photographs might be used in association with other navigational aids. Barnard et al.[129] also began with a job analysis in investigating helicopter tactical map requirements. An alternative aspect of task descriptions is to start with a specification of the content of the map, from which deductions on the tasks which could be performed using such information might be made (Summerson[122]).

The procedures for compiling task descriptions in relation to maps are quite standard. Havron and Jenkins[428] emphasised the evolutionary aspect of task descriptions whereby an initial compilation may be checked, verified and amended, and this procedure may be continued for some time to find a correct task description at the level of detail required. An aid to ensure that task descriptions are comprehensive is a check list. Task descriptions for maps may treat maps as displays in many respects and employ one of the check lists compiled in relation to display design and evaluation (Sinaiko and Buckley[429]; Singleton[110]). Task descriptions may be considered in the broader context of the whole man-machine system during flight, in which case the principles for evaluating such systems become applicable (Meister and Rabideau[430]). Sometimes guidance for task descriptions may also be obtained from general cartographic sources not initially related to aviation. An example is the discussion of problems of terrain representation by Sherman[431] who enumerated sequential decisions to be taken about how relief should be portrayed.

A further approach is to ask map designers about the design principles which they follow and the purpose which they serve. When McGrath[432] did this, he found that the design of aeronautical charts was greatly constrained by the radio navigation aids available and by air traffic control regulations governing traffic on airways. Payne[427] was among other earlier researchers who had concentrated on map design in relation to air traffic control problems.

The analytical or synthesising approach may be used for task descriptions in relation to map display technology. It is possible to start with the classes of display technology available and deduce from this what tasks each could best fulfil (McGrath[433]). Alternatively it is possible to start with the operational needs and task requirements and then to deduce and specify the information needed for each task. Knowing this, it is then possible to decide what would be the most efficient display technology to employ to present it (McGrath[356]). These alternatives are not necessarily conflicting or contradictory but the first is restricted to the display technology available at the moment, and the adequacy of the second approach depends on a thorough knowledge and competence not only in task description, compilation and methods but also in the map display technology available and the constraints which it imposes.

Hopkin[70], outlining the human factors display principles used in the compilation of an experimental map sheet, noted that this process of testing the relevance of human factors display principles to map design was not a replacement for user opinion or job and task descriptions, which were still essential. The purpose of the experimental map was essentially to test whether human factors principles were applicable to the design of maps and to provide guidelines on which principles could be applicable as they stood, which were not applicable, and which might be applicable after modification. A comparative evaluation of the experimental map is reported by Taylor[100]. The work of Murrell[131] is also pertinent to task descriptions, although not conducted for that purpose. Asking users what information they consider necessary for a task produces answers in the form of legend categories and hence in predetermined cartographic terms. Murrell[131] adopted a different method, and asked aircrew which specific items on small sections of map they would require for a given operational role. The results were different from those obtained by asking questions about legend categories and were interpreted as being a more valid method for defining users' needs and hence for compiling task descriptions.

Wright[314] considered light military aircraft and the users' requirements in them. He found that detailed task descriptions were essential to understand the pilots' role and also to draw up an adequate specification for reflecting very different degrees of complexity of equipment required. Simple equipment may be essential, for instance, in helicopter

operations, whereas very complicated equipment may be equally essential for alternative roles requiring radar-map matching. Cummins[328] has also provided a discussion of methods and criteria to be followed in describing user requirements for maps. Miller[312] singled out maps and map displays as being inadequate for low altitude operations because the problems of the pilot and his role as a component of a man-machine system had not been adequately considered in relation to cartographic support. Farrell[358] has discussed measurement criteria in assessing performance of helicopter pilots and Strother[362] was concerned with the visual activities of low flying helicopter pilots which would form a part of the task description for such pilots. Evaluations of new map types such as military photo maps depend considerably for their results on the choice of tasks since some are performed better with photo maps and some with conventional line maps (Hill[434]). Detailed task descriptions based on user requirements can be used to study and classify the missions and considerations under which a photomap might be more effective than a topographical map. Ultimately, task descriptions may reveal needs which cannot be fulfilled. Wood's[435] study of statistical terrain analysis illustrates the gap between the practicality of such methods and the need to discover and apply principles for terrain classification which would enable information of military use to be produced quickly.

Despite extensive discussion on the value of task descriptions in relation to aviation maps, the fact remains that such descriptions have never yet been compiled as thoroughly and as systematically as they could have been. They must be thorough and systematic in order to realise the full potential of the task description method. The provision of adequate comprehensive task descriptions in relation to aviation maps would be a great benefit to all concerned but it requires a broad co-ordinated approach to replace the piecemeal one adopted hitherto. Good task descriptions serve many useful functions. At present we have inadequate knowledge both on the details of how maps actually are used and on how they could best be used in relation to developments in modern display technology.

6b BRIEFING TASKS

Briefing and flight planning are the two main activities involving maps that take place before a flight commences. Briefing is mainly concerned with the dissemination of information to aircrew who are about to fly a mission. Planning refers to the work involved in preparation for a mission and in making decisions about achieving mission objectives. Some form of briefing on mission objectives must always precede flight planning, if only in the submission of mission tasking details, and a final briefing will often follow the planning of the mission, particularly when more than one aircraft is involved. The detailed content and sequencing of briefing and planning will vary in different operational roles, in different aircraft types and in different squadrons. Although certain Standard Operating Procedures (SOPs) must always be followed, notwithstanding these the procedures used on individual squadrons will vary out of necessity with the specific mission to be flown and the time available to prepare for it. It is outside the scope of the present volume to consider all possible variations in briefing, planning and other aircrew tasks involving maps. For up-to-date information on specific procedures the reader is directed to other sources where they are dealt with in more detail such as Bruce[385] on current procedures for low level strike sorties, and Barnard et al.[129] on low level helicopter operations. The purpose of this section is to draw attention to main differences in how maps are used by aircrew and to consider how well maps are adapted to these diverse tasks.

Depending on the circumstances of the mission, a briefing may take the form of a self-briefing, where the individual instructs himself on mission relevant information, for example if he is required to return quickly to an area without leaving his aircraft. More commonly the briefing will be given either informally or formally by a flying instructor or flight commander with other aircrew in attendance. In a war-time situation, pre-planned routes will be extensively used by low level strike aircraft to ensure quick response, and aircrew must keep a continuous, up-to-date brief on the requirements for these missions. Briefings may also take place in flight in multiplace aircraft, for instance when the navigator instructs the pilot about changes from the planned route due to evasive action, geographic disorientation or a changed tactical situation.

The kinds of information that may be included in a briefing could cover the following areas:

(1) General mission objectives and tactics.
(2) Call signs.
(3) Composition of flight.
(4) Armaments and fuel.
(5) Fuel checkpoints.
(6) Radio frequencies.
(7) Timing of mission.
(8) Current and expected meteorological conditions.
(9) Warnings, e.g. parachuting.
(10) Restrictions on flying procedures (e.g. peacetime requirements).
(11) Restrictions on aircraft (e.g. maximum flap settings at particular speeds).
(12) Emergency procedures following equipment failures, loss of contact etc.

Much of the information contained in the briefing reiterates the original task obtained from the operations control centre concerning aspects of the target, mission and aircraft. If the sortie has already been planned, detailed information on the sortie content and on the target, fire position or line of search may also be given. This may include: the location

of enemy and friendly forces; waypoint, target and fire position co-ordinates; rendezvous points, initial points, pull-up points; sectors of fire, attack headings, cross-over, run-out and evasion tactics; defences, terrain and sun positions; diversionary airfields. Where necessary this information will be illustrated by diagrams drawn on a blackboard, which are copied onto a map or knee pad by aircrew attending the briefing.

In the case of a final review briefing for a low level strike mission the detailed flight planning will probably be complete, and the aircrew will have copies of the route drawn on their maps for reference and annotation, during the briefing. In other aircraft operations such as low level helicopter missions, route planning and map preparation may take place after the mission briefing. Map study is an important aspect of pre-flight briefing and this may take place during the preparation of the maps or at any time thereafter. The aim of map study is to memorise the route and to visualise the likely appearance of waypoints, identification points and targets.

Debriefing sessions after a mission may be formal or informal. The purpose of a debriefing may be to review the conduct of the sortie and the problems which occurred, to discuss their implications for future tactics, and to pass on information about enemy positions and defences, useful identification features, possible fire positions, entry and exit routes, and available cover and line of fire. Most of this information can be conveniently recorded on a map.

In the past, most topographical maps were able to make some contribution to briefings. Map scale was the main determinant of information content and, provided that the appropriate scale of mapping was available for the area, a map would form the basis for the mission brief. In the future, map content is less likely to be a simple function of map scale. Maps will become more specialised in terms of the functions they fulfil, and different contents probably will be found on maps of the same scale. Under these circumstances it may be necessary to produce special maps for briefing purposes.

In general, maps have not been designed with briefing in mind and the experimentation done on this topic is very limited. The literature has mainly been concerned with effectiveness of maps as aids, in sensor or reconnaissance information interpretation. A series of studies at the USAF Personnel and Training Research Centre by Lichte and his colleagues considered the effectiveness of maps as aids during radar bombing (Daniel et al.[54,55]; Lichte et al.[57]; Lichte[58,59]). The task involved direct comparisons between the map and the radar imagery in flight, and the major map variable investigated was map scale. The method of displaying the map, its detailed content and coding, and the instructional technique were not varied independently. A study by Welch and McKechnie[436] compared the identification of various targets on sideways looking radar by navigators with various briefing levels, some of which included examination of a map beforehand. Their findings that map study made no difference to the successful finding of targets on the sideways looking radar imagery was interpreted to mean not that maps were irrelevant to sideways looking radar or that briefings were unproductive for missions using it, but that new briefing techniques and new briefing material will have to be developed to make sideways looking radar imagery more intelligible. McKechnie[437], in a further investigation, found that information about the nature and location of targets on sideways looking radar imagery enhanced performance in detecting targets whereas even gross changes in the simulated velocity of the aircraft did not have a great deal of effect on the general proportion of targets detected. In a further study (McKechnie[218]), he was more specifically concerned with maps and compared maps with electronic indicators as briefing aids. The introduction of maps on which the required targets were circled led to dramatic improvements in the detection of targets on the sideways looking radar imagery, though not in the time taken. More generally, Parkes reviewed the evidence from a number of studies which indicate that target acquisition performance is very dependent on the nature of the briefing information available beforehand. He conducted an experiment which showed that oblique photographs of a target and its surrounding terrain provided the most effective form of briefing information, but that perspective views derived from map information were also beneficial and indeed were better than the map information alone.

While briefing tasks feature to some extent in surveys of map users (Lakin[340]) and also in studies of how information on maps is actually used (Murrell[131]) all such work puts the main emphasis on the use of maps during flight. Similarly although Taylor and Hopkin[151] have compared the accuracy of locating pinpoints using grid references or verbal descriptions of topographical information, the envisaged application of this study was during flight in forward control operations rather than during pre-flight briefing, although many of the factors studied were relevant to both situations. The use of UTM and lat/long co-ordinates during pre-flight planning and briefing was considered to be a source of problems by Bruce[385].

The application of human factors principles to the role of maps in briefing has therefore been a much neglected topic. Certain principles and recommendations which can be suggested depend on the application of existing human factors knowledge and on the supposition that it generalises, rather than on detailed studies specifically evaluating maps for briefing purposes.

A good briefing has to be fully intelligible as given. This means that either it must develop its own frames of reference so that the person giving the briefing does not rely on his beliefs or assumptions about what his hearers know or how they think, or it must utilise what is known about instructional techniques, mental imagery, and human memory and about the method inculcated during training for absorbing and interpreting briefing information.

A certain amount is known about instructional techniques using maps and aerial photographs to educate school children and adolescents (e.g. Muir and Blaut[439]; Gildea[440]; Bartz[441]). Research is needed to test how far this applies to adults and to examine the validity of these methods to aircrew briefings.

70

The relevance of mental imagery to pre-flight briefing was recognised by Dornbach[292] who wrote: "the better the mental map is established through pre-flight study, the easier is pilotage navigation during an actual mission". Dornbach believed that by analysing the mental image requirements of the user, sound fundamental principles for map design would emerge. The cartographic product must be compatible with the user's mental imagery. In relation to imagery therefore the map has two separate roles. In one case it can be used to generate imagery and provide a basis for it. In the other it may be used to supplement or amplify an existing image. Although both processes may be well developed in skilled users there is no practical guidance on how maps and images are best matched. Although it would be hypothesised that the most efficient maps would acknowledge the limitations of mental imagery and encourage its optimum use, individual differences may be so large that such a proposition is not practical. Certainly untrained mental maps can be quite primitive. One of the functions of navigation training is to develop and standardise the mental maps of aircrew. Topographical maps are the main training aid in ensuring this uniformity. If despite these efforts, mental images of aircrew are found to be disparate then the effectiveness of any map design based on principles of human imagery will be very dependent on the characteristics of the individual, perhaps sufficiently so for cartographic specifications based on knowledge of imagery to be fruitless.

However, it is probable that the mental images of experienced aircrew are quite similar and the general principles could be derived on how maps should match them. If maps are used as a means of generating and understanding images then maps similar in content, and preferably the same maps, should be used before, during and after flight to maintain the match between images and maps as well as possible. It would be expected that as a general principle maps which were matched to mental images would be easier to memorise and that they would tend to be more pictorial than other maps, particularly in relation to terrain depiction, use of colour and choice of symbology. Furthermore, it would be expected that the content of such maps would be well-matched to mental images of aircrew who are familiar with the area, probably emphasising features of navigational and operational significance and de-emphasising features of little or no relevance.

The ability to commit the information to memory and to recall the information in flight is vital to the success of a briefing. Adoption of standard operating procedures reduces the amount of information that must be memorised prior to each flight. Memory aids such as jottings on knee-pads, annotations on maps, and standard navigational forms can provide useful cues in the recall of briefing information. Training should ensure that these facilities are used in the optimal manner. Factors such as the organisation of the briefing and the use of visual and verbal emphasis are likely to be important. The availability of reconnaissance imagery, three-dimensional models of target areas and radar predictions, and the opportunity for simulated sorties in similar terrain or on simulated radar are additional factors that are likely to improve anticipation and recognition performance in flight.

Maps in general may be easier to interpret and memorise than most other forms of imagery because each element has a clearly designated meaning. On the other hand, practical limitations on the size of map legends and on coding categories reduce the accuracy of representation of features to broad topographical classifications. These limitations may be acceptable when the classifications are based on operationally relevant criteria. When they are not, they may interfere with memorisation and visualisation of important characteristics. Place names may have little operational significance for most purposes, but in certain circumstances major place names may facilitate memorisation and recall of route planning information by providing a unique, meaningful spatial structure based on verbal rather than visual cues. This may be affected by the ability to verbalise the place name, a task that is not always easily accomplished for towns in foreign countries. There is some evidence to suggest that verbally coded information may be easier to recall than visually coded information. If this is the case, briefing techniques and cartographic representation that facilitate verbal coding of visual-spatial map information may be beneficial to subsequent recall during flight. Directing attention to features such as a T-shaped wood or a U-shaped river bend are typical examples. Verbalisation of topographical features and the use of descriptive cues are memory aid techniques that could be used by both briefing officers and by the aircrew receiving the briefings. Active involvement in preparing the maps, preparing the briefing, and in copying information received during a briefing is likely to facilitate subsequent recall. In this respect automation of these functions may be disadvantageous.

It tends to be assumed that the map information appropriate for briefing is that which will be appropriate for the mission. While this may be so it requires proving. Cases may well arise in briefings were there is a need to draw attention to misleading features or ambiguous features on a large scale map and it is possible to conceive that the operation might be more efficiently conducted if these were absent from the operational map in certain cases. Similarly as a means of locating and identifying checkpoints in briefings it may be helpful to be able to use local place names which serve no useful purpose once the target has been identified and would cause clutter on the map during the mission. The whole question of whether the same map should be used at every stage of a mission from briefing, planning, conduct, debriefing and other subsequent functions has never been systematically examined. Questions on what information the man needs to fulfil a mission have tended to produce answers which give the minimum information necessary during flight, to find a target, to check a waypoint, to navigate along the route and so on, but they do not usually refer to the optimum amount of information necessary for positive detailed briefing.

A further aspect is that the relationship between the maps and collateral material in briefing may be quite different from the relationship between maps and the collateral material available during flight. For example, at briefing various photographs taken at very different heights from that at which the mission will be flown may be available. There may thus be a case for relating intelligence information during briefing to a cartographic product which is different in scale and content from that used in flight. Once this has been used, it may then be necessary to consider the sensor information

which will be available during the mission such as radar, infra red line-scan or sideways looking radar and to select a map compatible with these. As with many of these questions there are probably no general answers valid for all circumstances but considerable improvements may be obtained by exploring how flexible the approach needs to be and making recommendations on briefing practices accordingly.

At a more practical level, the efficacy of a map during briefing will depend on how suitable the map is for annotation, and whether the form of the briefing lends itself to such annotation. Reverse format, black maps, for instance, lead to annotation legibility problems with conventional map marking pens intended for white or light background maps. Locations given in grid or lat/long co-ordinates may produce problems with maps that have only one co-ordinate system. Printing maps with both co-ordinate systems or providing aircrew with a calculator device to convert rapidly between the co-ordinate system are possible solutions. Finally, when maps are used by briefing officers in front of large audiences, legibility problems are likely to occur if the maps are viewed at greater than the designed viewing distance. Few topographical maps are designed to be legible at long viewing distances. This problem can be overcome by using transparencies of maps projected at larger than the original map scale.

6c ROUTE PLANNING TASKS

Although the success of most missions is crucially dependent on careful planning beforehand, very little research has ever been done on the function of maps for route planning or on the design of maps to facilitate route planning. This is despite the fact that firm evidence has existed for many years on the value of careful preplanning and check point selection to improve in-flight navigation, particularly at low level (Anderson[442]). The serious neglect of this research topic is not easy to explain because it is often simpler to conduct experiments about route planning than about in-flight navigation.

A very large variety of route planning tasks are conducted in aviation which may be broadly classified under several headings. There is a major distinction to be drawn between planning for civil commercial flights in controlled airspace along designated routes and airways, and route planning under relatively unrestricted conditions where the pilot has considerable freedom in deciding how he should reach his destination. A further fundamental distinction is whether the aircraft is a single seater or has more than one crew member. This determines the extent to which route planning or modification to the original route can be carried out in flight, and the extent to which pre-flight planning tasks can be delegated to other crew members. On low level strike missions for instance, navigators may be given the responsibility for planning the en route legs, whilst the pilot plans the final initial point (IP) to target run.

A further distinction is that between missions where one or more than one aircraft is involved. With a single aircraft the criteria adopted in route planning may be near optimum for the particular aircraft and conditions. When a formation of aircraft are involved, for instance, or a two aircraft line-search reconnaissance sortie, the flight planning needs to take account of flying techniques such as cross-over turns, and to ensure a good distribution of the search task. On a strike mission the planning may need to ensure the optimum positions for the aircraft during the attack run on the target. Furthermore when the route is planned by one individual, usually the flight commander or formation leader, copies of the route may have to be made for other crews in the formation. Other considerations relevant to flight planning include the need to plan for secondary objectives, the return leg, and procedures for dealing with emergencies, loss of contact and geographic disorientation. The content of flight planning will vary with the differing flight profiles and objectives of different aircraft roles, with the time available from mission tasking to take-off, with the relevance of Standard Operating Procedures, with the altitude flown and with the operational conditions, such as peacetime, wartime, training, competition, exercise.

Thus many factors determine the exact purpose and content of planning, how much can be precisely determined in advance and how much must be left to tactical decisions at the time. Nevertheless, every mission requires some planning in advance. Normally this planning involves maps. With the exception of only a few aircraft roles, such as air defence, maps always form the basis of flight planning. Where the mission involves cross-country navigation, maps provide much of the data needed to plan such missions, and they are the most suitable medium for recording, storing and displaying route plan information for pre-flight, in-flight, and post flight purposes. A paper map showing the flight plan is invariably carried on aircraft during cross-country navigation although the extent to which it is used in flight depends on the equipment fitted to the aircraft. Even when the most advanced navigation aids are available a paper map will still be necessary in the event of equipment failure during flight or if the aircraft becomes progressively less serviceable during a wartime situation.

Barnard et al.[129] distinguished the following tasks involved in flight planning for helicopter operations and also involved in planning most aircraft missions.

(1) Assessing the implications of the tactical situation.
(2) Assessing the implications of the meteorological forecast.
(3) Assessing the terrain from the map.
(4) Choosing the route, including rendezvous (RV) points, initial points (IPs) and Fire Positions.
(5) Defining flight procedures, including height, speed and formation.
(6) Organising fuelling arrangements.

(7) Defining emergency procedures and alternative routes.
(8) Identifying useful navigation features.
(9) Marking up the map with relevant information.

The basis for most of the topics listed above is the ability to correlate verbal, written and diagramatic data, to identify factors relevant to the mission, and to develop a full understanding of the current situation and the implications of new data and known constraints.

Borden[443], considered low altitude high speed missions, and distinguished between tasks involving maps during the preparation phase when the appropriate cartographic materials are selected, and during planning when the best en-route course and best approach to the destination or target are determined. The author listed the kinds of knowledge required to select the appropriate cartography. They included knowledge of the relationships between chart scale size, shape generalisation and density of portrayal features, knowledge of vertical and horizontal accuracies of portrayed features, and knowledge of the intelligence base from which the chart was compiled. For tasks carried out during the planning phase, the following tasks were listed, in their approximate order of importance as judged by experienced operators and research workers.

(1) Predicting the appearance of features viewed from the planned route.
(2) Determining terrain shape.
(3) Predicting the visibility of terrain features.
(4) Recognising barriers, funnels, general orienting features, and features that can aid in re-orientation if off-course.
(5) Recognising patterns of features that will aid identification of check-points.
(6) Selecting features that will break from masking at sufficient distance ahead to allow positive identification.
(7) Predicting the detectability of terrain features.
(8) Determining the intervals for selecting check-points.
(9) Infering unportrayed features, such as vegetation cover, presence of a bridge, railway junction etc.
(10) Selectively attending to one class of information.

The first task in flight planning or map preparation is to identify the maps available for the area and to withdraw them from store. Maintaining adequate stocks is essential to flight planning. In low level strike missions for instance 1:500,000 scale maps are normally used for route planning and 1:50,000 maps are used to plan attacks on targets. The 1:500,000 scale maps are often covered with transparent plastic for repeated use, but 1:50,000 target planning maps are usually discarded after use. In low level helicopter operations, 1:250,000 scale maps are more commonly used for planning the en route transit phase. Once the relevant maps have been obtained they may need to be cut and joined to provide continuous coverage of the route during flight, and the frequency with which this has to be done will depend on the mission length, the scale of the map series and the size of individual map sheets. In the worse case, four map sheets may need to be joined together to cover an area in the corner of one of the sheets. Map borders, including legends are usually removed to reduce the bulk of the map.

After the process of selecting, cutting and joining maps, which may take several minutes, the map may be marked with permanent aeronautical information not included on the map, copied from some other map scale (e.g. 1:500,000 Low Flying Chart), from a master chart maintained and updated by the flight planning officer, or obtained from the briefing, from NOTAMS (Notices to Airmen), or from information posted in the crew room relating to the local area. These additions may include the following information.

(1) Restricted and danger areas.
(2) Local low flying area boundary.
(3) Low flying routes.
(4) Sensitive areas (e.g. mink farms; bird sanctuaries).
(5) Special routes.
(6) Control zones and special rules areas.
(7) Radar let down lanes.
(8) Glider and parachuting sites.
(9) Airfields.

Certain annotations may be made to facilitate map reading. Obstructions and power lines may be highlighted for flight safety reasons. Grid lettering may be highlighted by adding a bright conspicuous colour (e.g. yellow). Town shapes may be coloured-in with a dark ink. Relief representation may be improved by adding some hypsometric colouring if not already present, and by drawing in ridge and valley lines.

In a typical low level strike sortie, the mission planning is divided into attack planning and route planning (Bruce[385]). Normally, the flight leader will plan the detailed attack on the target using a 1:50,000 scale map marked with the target and known defences. In choosing the direction of attack and the initial point (IP) several factors will be taken into account.

(a) Target photographs, when available.
(b) Geographical features providing concealment and ease of recognition.
(c) Disposition of enemy defences.

(d) General arrival direction.
(e) Direction of the sun.
(f) Type of weapon to be used. This affects the attacking height and length of run.

The optimum attack plan is chosen by weighting these target factors, relying entirely on the skill and experience of the pilot.

The target and IPs are then identified on the small scale route map (usually 1:500,000) and the pilot (or navigator) then plans the route from take-off to the target and back to base. The choice of route may be constrained by a variety of factors including the terrain, known defences, friendly corridors or prohibited areas. In general the safest and most economical route to the IP is chosen to incorporate check-points and turning points at easily recognised, prominent features. Legs, turning circles, and timing marks are drawn using customised rulers. Assuming a constant ground speed, times may be specified at various points along the route, such as time over target, time over friendly corridors, time over forward edge battle area (FEBA). A "time gate" measured precisely in seconds may be set up at a particular point along the route. Typically, 10 legs may need to be drawn on the map and time for each leg is determined by measuring the leg distance for constant ground speed. Safety altitudes may be recorded for each leg and estimations of fuel state may also be marked at intervals along the route. Again the pilot's skill and experience must be relied on to weigh all the relevant factors that determine the optimum route. McGrath[339] gives a detailed summary of the problems of chart interpretation in low altitude flight that is intended to be a training aid for aircrew.

In other aircraft roles, involving long range flying, such as stategic bombing and transport missions, flight durations may be much longer and as many as 30 flight legs might be involved. Route planning for these missions may take up to an hour to complete. In such roles, instrument navigation and dead reckoning techniques are likely to be preferred to map reading wherever possible. In helicopter operations, such as casualty evacuation, the timing of the mission may not be as critical as for strike operations, and planning for transit phases may not be as detailed as that described above. Barnard et al.[129] summarised the different planning procedures involved in helicopter transit flying, above and below 200 ft altitude. At low levels, the emphasis in planning is on visualising and memorising the route and key features, on checking for obstructions, on terrain masking, on using cover, and on highlighting significant detail. At higher altitudes, during transit flying, the general approach to flight planning is to select a heading directly to the destination or to some prominent local feature, and to add distance markers, e.g. 10 miles to go, ½ mile to go, ¼ mile to go, etc, and, only occasionally expected times at these marks.

Once the route has been chosen and the map marked-up with tracks, turns, timing marks, fuel estimates etc, excess map may be cut away and the remaining strip folded to facilitate handling in flight.

It can be argued that for pre-flight planning purposes information may sometimes be required in a form which gives far more detail than is appropriate for flight. It seems likely that a far greater range of information is needed to plan a route, select suitable waypoints and reject unsuitable tracks than it is to confirm a route during a flight and verify the waypoint that has been reached. In most roles limitations on time in flight prevent detailed map reading and make clutter a serious disadvantage. These constraints need not influence the design and content of maps used for route selection tasks during pre-flight planning. It is noteworthy that in most attempts to validate maps for their purposes the emphasis has been on whether the particular map enables the mission to be successfully accomplished rather than on whether it has enabled it to be optimally planned. Very often planning tasks have not featured as they should have done in influencing the specification or evaluation of the map.

Osterhoff and McGrath[133] concluded from their studies of pilot performance using different charts that the relative effectiveness of maps was specific to the terrain over which the crew had to fly. Characteristics of the terrain determine how routes and missions should be planned as well as the accuracy with which they are flown. Very little consideration has been given in the design of maps to the different procedures for route selection in different kinds of terrain. This is primarily a matter of choosing the optimum map information content although the effectiveness of planning is determined by the methods of presentation also.

6d TASKS DURING FLIGHT

As in briefing and pre-flight planning, the nature of tasks using maps during flight is influened by many factors which makes it difficult to derive a single coherent taxonomy, and to some extent limits the usefulness of any taxonomy that could be derived. Operational factors, such as those listed in Chapter 4a are clearly relevant; viz, day or night flight; visual flight rules (VFR) or instrument flight rules (IFR) flight phase; flight profile; operational role; crew constitution; type of aircraft and navigation system. The most important factors may be summarised as follows:–

(1) Tasks vary according to operational role and aircraft type, whether military, civil commercial or general aviation, and fixed or rotary wing; according to the navigation facilities in the aircraft and on the ground, and the sophistication of on-board sensors; and according to whether the flight is through controlled or uncontrolled airspace, using IFR or VFR procedures.

(2) The tasks which can be done with maps, and their allocation, depend on whether the aircraft is single or multi crew, and, if the latter, on the number of crew and on the envisaged division of their responsibilities, as reflected in the workspace design and the facilities at each position.

(3) Tasks, and their pacing and urgency, depend on the adequacy of briefing, on the opportunity for pre-flight planning, on the flexibility and need to adhere to the flight plan, and on the flight duration. All these factors influence the division of map-related tasks between pre-flight and in-flight phases. They also affect the amount of mapping which may be needed in flight and the range and flexibility of mapping problems which may arise.

(4) External visibility, aircraft height and speed affect the use of maps in flight, either directly by limiting what can be seen on the ground and by restricting the time within which tasks must be done, or indirectly by inducing physical conditions such as buffeting which limit what can be seen on maps or what can be done or calculated using them.

Tasks involving maps are only part of a wide range of activities involved in flight. Latham and Spencer[424] carried out an analysis of navigator activities during operational bomber sorties and identified twenty-one tasks, listed below in order of percentage of total time spent at each task by the navigator:—

(1) Plotting (20%).
(2) Logging (19%).
(3) Resting (13%).
(4) Checking and planning (12%).
(5) Intercom (7%).
(6) Odd jobs (6%).
(7) Computer W/F (4%).
(8) Watch (4%).
(9) Computer calculations (3%).
(10) Transition (3%).
(11) PPI observation and operation (2%).
(12) GEE operation (2%).
(13) Eating (2%).
(14) API (1%).
(15) Hunting (1%).
(16) ASI, ALT, Temperature reading (1%).

Map reading, along with drift sight, VSC, VCP, DRC, ANT, and documents, each accounted for approximately 0.5% of the total time. The radar operator had a different range of activities, and spent approximately 7% of his total time map reading. Experienced navigators spent approximately 3% more time map reading than inexperienced navigators. Records of head and eye activity of pilots have shown that 27% of the time may be spent map reading during low altitude, fixed wing operations (Lewis[66]; Lewis and de la Riviere[360]). Experienced helicopter pilots have been observed to spend 14.7% of the time looking inside the cockpit during low altitude, nap-of-the-earth flying, out of which 8.5% was spent checking instruments, 5.7% map reading, and 0.5% in radio operation. Over a less familiar route, time spent looking inside the cockpit increased to 26.5%, with 11% on both radio operation and map reading, and 4.6% on checking instruments (Lovesey[361]). Thus it is evident that the contribution of map tasks to the total pattern of activities carried out in flight varies between different aircraft operations, between different aircrew in the same aircraft, and between similar sorties over different terrain.

Many map-related tasks normally carried out during pre-flight planning may also take place during flight, either because of insufficient pre-flight planning time, revised or new mission tasking, changed tactical situations, or system failures and emergencies necessitating modification or abandonment of the flight plan. In-flight planning is less likely to occur in single-seat aircraft than in multi-place aircraft where it can be done by a navigator without interfering with the control of the aircraft. In helicopters, revisions to the flight plan can be made by setting the aircraft on the ground. Most of the basic map reading tasks and skills involved in map interpretation, checkpoint selection and anticipation, and relief visualisation are common to both pre-flight and in-flight phases. Pre-flight planning may be intended to reduce the need for map interpretation during flight, so that in flight the map is merely used as a memory aid. Nevertheless, each time the map is scanned, no matter how briefly, the basic perceptual tasks of detection, discrimination, recognition and identification must take place before any judgement can be made about the position of the aircraft in relation to the flight plan.

Geographic Orientation

In flight, the primary function of maps and charts is to facilitate the task of navigation, or more fundamentally, to maintain geographic orientation. Geographic orientation has been discussed in detail earlier in Chapter 3c. Lichte et al.[56] described geographic orientation in flight as maintaining a sense of direction, a sense of one's position in the geographical environment, and a sense of the pattern of the physical and cultural features of the surrounding world. McGrath[316] described geographic orientation as the task of ascertaining and apprehending the aircraft's position in relation to geographical points, and regarded it as a fundamental requirement of any aircraft mission. McGrath argued that geographic orientation is a special form of spatial orientation, different from the spatial orientation that the pilot obtains from a vertical situation display. Whereas the vertical display relies on the pilot's learnt perceptual ability to orient himself to the visual world, in geographic orientation the pilot orients himself to cues outside his direct perceptual experience, to a space he has never seen except in abstract form on a map. In goegraphic orientation, McGrath argued, the individual extends his immediate visual world to include the world he cannot see, and perhaps will never see, and becomes oriented to both the immediate and un-sensed visual world in an integrated process.

Navigation

In contrast to such complex psychological interpretations of the process of geographic orientation, the task of aerial navigation has been described elsewhere in methodical terms as "a clear-cut, logical application of simple scientific principles to the task of directing an aircraft through the unmarked skyways" (Carter[423]). Strictly speaking, the navigation task involves the determination of course, position and corrections in heading. Course is determined by locating the departure point and destination (or start and end of a flight leg) on a chart and measuring the direction between them. Position is determined by identifying where the aircraft is at a particular time, either by positive identification of a ground feature or by computing the distance and direction flown from a known position, and by predicting where the aircraft will be at any given time by computing the distance and direction it will have flown from the last known position. Corrections in heading are determined by finding the corrections necessary to maintain a desired course or to reach a destination. Corrections are based on information from four sources:–

(1) Navigation instruments in the aircraft.
(2) The ground.
(3) Radio observations.
(4) Celestial observations.

Dead Reckoning and Pilotage

The basic method for solving navigation problems is dead reckoning, whereby the aircraft's approximate position is calculated by relating information on the time, distance and heading flown to the last known position. Effects of wind force and wind direction on the heading and speed of the aircraft can also be estimated. The position estimated from dead reckoning can be checked by three methods:–

(1) Map reading, pilotage, or visual reference to the ground.
(2) Radio and electronic aids.
(3) Celestial observations.

When flying over land, the most accurate check on dead reckoning is pilotage or map reading, comparing features on the ground with features marked on a map. When two check-points have been definitely identified the navigator can use time, speed and distance information to obtain a gound speed and determine an estimated time of arrival at the next check-point or destination. Alternatively the navigator may determine the speed required in order to arrive at the next check-point or destination at the planned time. Carter[423] considered that the unique and difficult part of pilotage (map reading) was identifying the two check-points on the ground and argued that the following five factors were important to this task:–

(1) Pattern recognition and discrimination: identifying a given terrain feature as being that represented on a map.
(2) Pattern recall: remembering a sequence of patterns so that their identity can be deduced after they are traversed. This is particularly important when an aircraft is lost or when cloud cover interferes with continuous observation.
(3) Direction orientation: the ability to identify a pattern in relation to the orientation of the map.
(4) Correct perception of contours: visualisation, depth perception and infering spatial relationships from contours.
(5) Time and distance relationships: knowing when to start looking for the next check-point.

Visual Referencing

The detection and identification of check-points, known at visual referencing, plays a key role in geographic orientation at low altitudes. McGrath and Borden[65] argued that the navigation keystone of low altitude flight is the pilot's ability to establish his position by visually detecting and identifying a geographic feature and referring that feature to its representation on his map. Only when the pilot has positively identified a visual check-point, does he know precisely and certainly where he is. Visual referencing may take place by comparisons of the map with the ground, or with ground mapping sensors such as radar and FLIR. Despite the importance of visual referencing, little is known about the specific perceptual cues and cognitive processes whereby the pilot converts check-point cues to an awareness of his position. McGrath and Borden[65] produced evidence that in low altitude operations visual referencing is essential to maintaining orientation, that it is the dominant cause, of disorientation, that it is the sole means of recognition of disorientation, and that it is the dominant means of reorientation. At low altitudes, the relative dependence on dead reckoning and visual references (pilotage or map reading) varies with the aircraft type, the effect of wind, and the difficulty in controlling the aircraft's heading. Visual referencing is more common in rotary wing aircraft than in fixed wing aircraft because of the comparative difficulty of controlling helicopters in flight. One of the pilot's main tasks on a low altitude mission in both fixed and rotary wing aircraft is to decide upon the correct balance between dead reckoning and visual reference. His decision will partly be based on the quality and frequency of check-points along the route, as indicated by a topographical map.

Whilst emphasising the importance of detecting and identifying check-points in low altitude flight, McGrath and Borden[65] refer to several other tasks involving maps during visual referencing. These may be listed as follows:–

(1) Selecting check-points from the map on the basis of their availability, reliability, perceptability and discriminability.

(2) Determining the frequency of check-points that is necessary to maintain orientation.

(3) Determining the number of individual features needed to make a reliable check-point.

(4) Maintaining a general orientation to distant non-specific visual references as well as check-points along the route.

(5) Counting sequences of check-points.

(6) Making use of funnel and barrier features and time gates.

(7) Maintaining geographic orientation during formation flying when not leading the formation.

Reorientation Procedures

Geographic orientation is normally maintained during visual referencing by map-to-ground comparisons, when the map is studied in advance to select, anticipate and facilitate identification of good check-point features. When a pilot is geographically disorientated and unaware of his position on the map, reorientation is normally achieved by scanning from the ground to the map, by identifying a good check-point feature on the ground and then finding its location on the map. In practice, both orientation and reorientation processes involve visual references identified initially on both the map and the ground. However, the greater proportion of visual references during orientation are identified during map-to-ground comparisons, whereas during reorientation more are identified from ground-to-map comparisons.

The most common procedure for reorientation during low altitude high speed missions is to adhere to the planned times, distances and headings, turning on time and onto the planned heading, until a reliable visual reference can be identified. This tends to minimise the error from the planned route, in terms of distance flown, fuel consumption and time to reach destination. Alternatively, in serious cases of disorientation the pilot may elect to gain height and obtain a wider field of view, allowing orientation to more distant, prominent features such as rivers and roads. Under operational conditions this exposes the aircraft to the enemy and must be avoided if possible, or at least kept to brief alterations in height. On military training sorties or in civil operations the pilot may contact air traffic control for assistance.

Barnard et al.[129] list several reorientation techniques used by helicopter pilots during low altitude, nap-of-the-earth tactical navigation. The most commonly used procedure was to retrace the route to the last known position and start again. Other techniques in addition to those already discussed include the following:–

(1) Flying towards a prominent, mapped, feature, diverting off track if necessary, and replanning the route from the location of this feature.

(2) Defining an "area of possibility" or "circle of uncertainty" and searching thoroughly within this area on the map for features corresponding to the ground.

(3) Flying in a pre-defined box pattern until a unique feature or group of features is seen.

(4) Ignoring minor features and only looking for major features.

(5) Looking for town names signs, railway station signs, road signs etc.

(6) Flying until a line feature is seen that can be identified on the map.

(7) Flying to a line feature on the map ahead of the aircraft, and then flying along the line feature until a position fix is achieved. In certain circumstances the pilot may decide to turn in a specific direction along the line feature to find a prominent feature that has been identified on the map.

(8) Landing the helicopter and studying the map and surrounding terrain in detail.

Distance Estimation

Distance estimation is often carried out with the aid of a map, particularly during helicopter reconnaissance sorties. Many aircrew develop techniques for estimating distances which rely on simple calibrations of the hand. Distances on a map are frequently estimated with the thumb or finger span, or by counting the 1 km grid squares on a 1:50,000 scale map. Some pilots judge distance on the ground by counting features in the foreground or as they pass beneath the aircraft, and then refer them to the map. Others may judge the distance of a prominent feature either by its size, its location on the map, or by how many football pitches for instance would span the distance, and then use this as a standard for estimating distances of other features. Experience is a major factor in determining performance on these tasks. With training and practice, sophisticated skills can be developed, including allowing for factors causing illusory distortions of distance such as visibility conditions and unfamiliar terrain.

Moving Map Display Tasks

Moving map displays, and their associated navigation systems introduce a new range of map related tasks that are not performed in simpler aircraft systems which rely entirely on dead reckoning and visual referencing for navigation.

Roscoe[166] identified the following major tasks associated with the use of moving map displays in flight:–

(1) Interpretation of surface mapping radar or other high resolution, real-time, image producing sensors.

(2) Updating self-contained navigation systems by reference to visual or radar position fixing.

(3) Initiating and interpreting in-flight system self-test routines.

As well as monitoring the aircraft's position, map displays provide a ready means for cross-checking positions obtained by visual reference and for evaluating the outputs of navigation systems such as doppler, radar, and inertial platforms. The map display is used to store a range of navigation data, and to enter co-ordinates and positions for subsequent display. Furthermore by acting as an interface between the pilot and the navigation computer, the map display is used to communicate with the computer, to check its integrity, update its accuracy, and to enter navigation problems. (McGrath[160]; Taylor[338]).

Carel et al.[196] conducted a thorough evaluation of operational requirements for moving map displays and commented that tasks which make use of cartographic information in flight can range from reading out the aircraft's position to flying computed steering commands presented in a map display. Their comprehensive listing of tasks carried out with map displays was as follows:-

(1) Reading out position.
(2) Matching the outside visual world with cartography.
(3) Matching ground mapping sensor data with cartography.
(4) Matching latitude – longitude readouts with cartography.
(5) Matching hand-held map strip cards and flight following card data with map display cartography.
(6) Evaluating stored threat data.
(7) Evaluating real-time sensed threat data.
(8) Following computed guidance paths.
(9) Updating navigation systems.
(10) Updating the flight plan.

The authors state that the most common map display task is reading out position to provide geographic orientation. In doing this, the pilot makes an implicit comparison between where the map display indicates he is and where he thinks he should be at a given time during the mission. Previously, this would have been achieved by comparisons of present position and planned position in latitude, longitude and time co-ordinates. Of the tasks listed, the authors point out that four require matching cartography with some other source of position data, either the ground viewed directly, or ground mapping sensors such as radar or FLIR, or other navigation position data such as latitude-longitude readouts, or pre-flight planning data. These tasks are the second most frequently occurring group of pilot tasks involving moving map displays.

Target Detection and Identification

The detection and identification of targets involves similar tasks to visual referencing during navigation. Map reading may facilitate identification of targets viewed directly on the ground or indirectly on ground mapping sensors such as radar and FLIR, only when their positions are known in advance and may be anticipated in relation to lead-in features and patterns shown on the map. Unlike visual referencing which relies on highly selective portrayal of prominent features at small map scales (e.g. 1:500,000), target detection requires the accurate and detailed cartography available at large map scales (e.g. 1:50,000).

Target detection and identification may be viewed as an example of the general problem of visual search with its numerous forms in aviation, particularly in aerial surveillance and vigilance (Morris and Horne[444]). It can be treated in terms of mathematical probabilities. The relationship between range of target, visual angle, aircraft speed and height, visibility from the aircraft, target characteristics, length of glimpse or target viewing, and probability of target detection, recognition or positive identification, can be expressed at least partly in mathematical terms and statistical probabilities, as can the area within which the target must be before it could be detected at all. Linge[445] for instance, has sought to use this approach to arrive at a cumulative probability of detecting a given target in a given area. The mathematical approach can be particularly profitable in operational analysis or system modelling, but it has limitations where the intention is ultimately to make recommendations on the preferred coding and content, which tend to be concerned with broad classes of symbols rather than specific features.

The use of different map scales for en route navigation and target identification introduces map handling problems during the transfer between maps. Barnard et al.[129] however, noted that the main problem was in adjusting to the different speed travelled across maps of different scale. The recent metrication change from 1 inch to 1 mile map scales to 1:50,000 in UK series has caused similar problems for aircrew with extensive experience with the former scale. Chart scale is known to influence aiming point location on photographs, with larger scale giving a better performance (Lichte et al.[57]), and to affect the ability of subjects to mark their own position on a map (Edmonds and Wright[308]). In most contexts, however, detection of a target depends mainly on the nature of the target and its contrast with the background (Bernstein[446]).

Reconnaissance and Surveillance

A further kind of task requires some form of surveillance or reconnaissance, involving searching or flying within a designated region. This may be systematic search of an area for a specific target, for a missing aircraft or for troop movements, or the task may be to survey an area continuously and to build up general intelligence data from reconnaissance information. In such missions, maps are needed to plot locations and to record what regions have and have not been searched, ensuring that the search pattern minimises unproductive overlaps of searched regions while revealing any regions which have been missed.

In such roles, the emphasis is often on dead reckoning procedures to ensure the systematic coverage of the region. This may impose a major navigational task if the requirement entails flexibility in navigation, to discover for instance how extensively troops are deployed within a region or how much activity there appears to be over a wide area. Maps can greatly affect the efficiency of the search or the compilation of information, for example by giving forewarning of what lies in a deep narrow valley which can only be glimpsed as it is flown over, and by indicating approximately what will be visible from a given position and height. The value of the map will depend on the specific purpose of the mission, and particularly on whether the map includes sufficient features of operational relevance to be employed as a basis for structuring the mission and recording its progress.

Communication

Positional information derived from maps and the ground is frequently communicated by radio: in describing the deployment of enemy or friendly forces during reconnaissance, in directing fire, in directing aircraft in forward air control (FAC) operations, or in describing ground features that can be used for cover during helicopter anti-tank operations. Positional information may also be communicated between different aircrew in the same aircraft and between different aircraft in the same formation.

Most positional fixes are given by grid references. When describing enemy positions during hostilities grid references are given in "clear" because it is assumed that the enemy knows their own locations. Positions of friendly forces are described in code. Veiled speech is another form of secure communication whereby features and positions are referred to ambiguously, implicitly or by inference, in a way that only the intended recipient of the communication will understand. Generally, simple and quick reporting procedures are preferred to veiled speech in order to minimise the extra workload.

Positional information may also be communicated in terms of prominent ground features, town names, or other general verbal descriptions. Often grid references may be used to confirm general descriptions and reduce the possibility of error. Clock (i.e. compass) reference may be used when the recipient is in the same aircraft, or in a nearby position. If the sortie includes prescribed reporting points, these will be referred to in position reports using names, letters or numbers without reference to the map grid. During FAC operations, latitude/longitude co-ordinates rather than grid are used to direct fighter aircraft to positions of initial points (IPs) because the aircraft's instruments operate in this co-ordinate system. During the final stages of an FAC sortie on from the IP to a target, information on target position can be communicated to the aircraft by the controller in terms of prominent features visible to both, without reference to a map.

A study by McGrath et al.[322] on plotting target positions on maps compared with accuracy of pilots in simulated low altitude, high speed flight with the accuracy of independent plotters listening to descriptions of target locations over R/Ts. The descriptions were transmitted by pilots in visual contact with the targets. Results showed that pilot/plotter teams were as accurate as pilots alone.

Grid referencing is subject to errors, particularly when positions are estimated without plotting aids. Guttman and Finley[420] showed that aircrew made errors in four figure grid references in 12% of the interpolations made in each co-ordinate. Additional sources of errors can be large, particularly when verbal communication of co-ordinates is involved (Baker[421]). The advantage gained from using general descriptions of topographical features is likely to be greatest when plotting aids are not available or are impossible to use, as in single seat aircraft. Taylor and Hopkin[151] described an experiment which evaluated the relative accuracy of three methods of reporting positions on a map: grid references; general descriptions; descriptions with grid reference. Grid references produced less accuracy and more gross errors than topographical descriptions, whereas the descriptions alone lead to more minor errors. The accuracy achieved using the grid was independent of the information density on the map, whereas greater density of cartographic information surrounding the position led to greater accuracy and less time with topographical descriptions.

6e OTHER TASKS

The commonest tasks used in map evaluation are those requiring search or target location. It is therefore not surprising to find research being conducted on the interaction between map characteristics and search efficiency. Searching efficiency is affected by partitioning by grid lines (Ericksen[447]) by techniques for feedback enhancement (Enoch and Townsend[448]), and by limited search time (Richman et al.[449]). Degrading an experimental map to simulate the effects of aerial haze on photographic interpretation leads to predictable decrements in performance and emphasises

the strong influence of peripheral visual stimuli on visual fixations during search (Townsend et al.[450]). Training improves the ability to extrapolate from known spatial relationships on the ground to their form when viewed from various angles in the air (Larve et al.[451]), and chart variables interact with viewing angle in target identification and recognition tasks (Lichte[59]). Smith's[452] study of angular estimation was in fact primarily concerned with headings, but Waller and Wright[350] showed that training improved the estimating of angles of drift drawn on maps. Enoch and Fry[197] briefly reviewed factors influencing search performance on complex displays, including maps.

McGrath[432] used interviews to derive design criteria for aviation maps and concluded that their main function was to enable the pilot to use radio navigation aids and to acquaint him with air traffic control requirements on airways. Air Traffic control demands different information on charts for different levels with consequent problems when changing level, (McClune[453]). Air traffic control positions commonly include a panel with chart information, traditional in design and content, though evolving from paper to electronically generated displays. A further possible application of maps in air traffic control is to provide background information on a plan position display based on radar-derived information. Most commonly such information is software generated and electronically displayed, but developments such as the rear port display enable this information to be put on a transparency and projected to appear on the display.

Air defence systems also require background map information, although it is debatable whether they could be counted as in any sense aviation maps. They have specialised requirements, which can be fulfilled following the normal procedures of task analysis and design. Similarly, there are human factors problems in the choice and portrayal of map information for battlefields (Harris[454]) and for combat surveillance (Devoe and Hoagbin[455]).

Ground based simulation tasks are often used to assess maps, and indeed many of the findings cited in this volume have been derived from simulation studies which can explore variables more thoroughly and systematically than is possible under flight conditions. McGrath and Borden[317] used cine film to replicate certain visual aspects of low level flying and to present difficult navigation tasks in order to study geographic orientation. They concluded that their analytical method should be generally adopted. McGrath and his colleagues (Streeter et al.[456]) have also conducted experiments on computer generated electronic map displays for terminal area navigation, and for flight simulation.

Maps are used in image interpretation tasks (Laymon[305]), and as an aid to photointerpretation, and as a means of scoring and rating photointerpreters (Kalk and Enoch[457]). The applications to aviation of advances in map design or technology lead to re-examination of approriate specifications, although there is sometimes some tendency for such developments to be made before the ways in which they could be used are appreciated (Miller and Summerson[342]).

In aviation, maps have many further uses. Associated with flight, they are used for debriefing, and the design of maps for briefing should include considerations of de-briefing also, since the same maps would normally be used. Maps are also used to render intelligible films, photographs, radar, side-scan radar, infra-red line scan, and satellite derived information.

They are also employed in simulation of flight, in simulation of tasks associated with flight, in space flight, in liaison with other services and agencies, and to render intelligible communications between air and air, between air and ground, and between air and sea. Obviously, maps are used for training in map use. Finally, maps are used extensively in designing and producing other maps.

CHAPTER 7

THE COMMUNICATION OF CARTOGRAPHIC INFORMATION

Comparatively recently in the long history of cartography, mainly since the mid 1960s, there has been a number of attempts to develop a theory of cartography and to systematise the process of cartographic communication (Board and Taylor[458]). Robinson and Petchenik[459] noted that in the fields of psychology, philosophy and semantics, the map has been used as a fundamental analogy in discussions of communication. Yet in cartography, the ideas first expressed by Wright[16] under the title "Map makers are human", were scarcely developed until stimulated by the publications of Moles[460], Board[461], Heath[147], Bertin[462] and Kolacny[463].

The development of models of the process of cartographic communication as a means of identifying components and relationships between operations has been a major concern of theoretical cartography. The concept of the model has become as fashionable in geography as it has in many other disciplines. Chorley and Haggett[464] in their definitive work on the subject, classified the functions of models as psychological, normative, organisational, explanatory, and constructional, and Harvey[465] illustrated the complexity and limitations of models, and some sources of confusion in employing them. Board[461] discussed the analogy of maps as models and proposed that if maps are treated as iconic or representational models both the making and testing of such models can be studied. He employed a model of a generalised communication system drawn from the communication scienc literature including the concepts of message signal, source, encoder, transmitter, noise, receiver, decoder and destination. The world and the cartographer constitute the source, the map is the coded "message", the signal is made of the "light waves" which make the message visible, the channel is space, and the receiver, decoder and destination are the eyes and mind of the recipient.

Kolacny[463] proposed a more specialised model, which incorporated the complex processes of selection and interpretation in both the source (cartographer) and destination (map user) (Fig.4). These processes produce a discrepancy between the real world and the views of reality held by the cartographer and the map user. Reduction of this discrepancy is a fundamental aim of cartography. In 1969 (Ref.463), Kolacny called upon the International Cartographic Association to set up a Commission on Cartographic Communication to deal with problems concerning the utilisation of maps. He listed the following tasks that should be undertaken by the Commission:—

(1) To elucidate the structure of the communication process of cartographic communication.

(2) To study the function of cartographic information and its practical importance for society.

(3) To define the demands which various social groups make on maps.

(4) To analyse the subjective conditions of map users.

(5) To analyse the environmental conditions under which maps are used.

(6) To study methods of work with maps.

(7) To establish criteria for optimal information content of the map.

(8) To establish criteria for optimum map symbols.

(9) To look for new types of efficient products of cartography.

(10) To popularise the employment of efficient products of cartography.

(11) To work out a proposal for an international centre collecting cartographic information essential for the publication of maps and disseminating it periodically.

In 1972, the General Assembly of the International Cartographic Association created Commission V, Communication in Cartography, with the following terms of reference:—

(1) The elaboration of basic principles of map language.

(2) The evaluation of both the effectiveness and efficiency of communication by means of maps with reference to different groups of map users.

(3) The theory of cartographic communication, i.e. the transmission of information by means of maps.

Ratajski[466,467], the chairman of Commission V, has constructed a further model of "cartographic transmission", similar to but more detailed then Kolacny's, to illustrate his conception of the research structure of theoretical cartography. Both Kolacny's and Ratajski's models of the transmission of cartographic information have been generally accepted as the basis for future work in this field (Salichtchev[468,469]; Woodward[470]; Robinson and Petchenik[459]). A few authors have departed from these initial information transmission formulations. Muehrcke[471,472] chose to characterise the

cartographic process as a series of transformations between the real world, raw data, map and map image. Here, the cartographer's task is to devise better and better approximations to a transformation where the output is equal to the input. Morrison[473,474] used the terminology of set theory to draw attention to the process of induction whereby information is obtained from empty space on the map, from relationships between symbols, without the cartographer necessarily being aware of this information. Both Morrison[473,474] and Robinson and Petchenik[459] utilise rectangular Venn diagrams as an alternative to modelling the linear flow of information transmission.

Information theory has been used to measure the information content of maps (e.g. Sukhov[475]; Srnka[476]; Balasubramanyan[254]). These studies fail to quantify the information that may be inferred from a blank space, and give no account to positional data. Robinson and Petchenik[459] conclude that as the information on a map is not a coded sequential message consisting of signals, measurements of information content and information transmitted cannot be effectively obtained with the techniques of information theory. On the other hand, Taylor[111] has demonstrated that in comparative evaluations of maps, information theory analyses of information transmission can be as effective as, and perhaps more effective than, conventional measures of map reading performance. It was suggested by Molineux[477] that attempts to define the nature and purpose of a map had laid bare the theoretical void at the heart of cartography; this in turn had led to the quest for a theory, which had often taken the form of considering information theory, as Molineux does. Cartography has recently adopted some aspects of information theory with a comparably uncritical acclaim to that afforded to the theory by psychology some years ago. Useful it can be; but as a univeral medium for dealing with the communication of cartographic data it has some major and elementary defects, not the least of which is the implication that a blank space on a map conveys no information.

The structure of the present chapter has been formulated in accordance with the information flow modelling of cartographic communication. From a discussion of the cartographer's intentions, it is proposed to cover cartographic language, the map, map reading and the user's interpretations in that order.

7a THE CARTOGRAPHER'S INTENTIONS

There are many published papers on what cartographers' intentions are or should be, and on the nature and efficiency of cartographic communication. These papers generally discuss problems and advance solutions, rather than reach definite conclusions, and they can be interpreted not merely as a questioning of the role and purposes of aviation maps, topographic maps, or maps in general, but as an aspect of the broader quest among geographers for an adequate understanding of the nature of geographical knowledge and of the processes of acquiring and using it. Harvey's[465] discussion of the nature of explanation in geography implies that maps have enjoyed an esteem as models of spatial structure and as the geographer's main data-storage system which has been exaggerated and not always warranted. He quotes Bunge's[478] suggestion that, if geographic information can be furnished at various levels of generalisation, maps would be at an intermediate level, between raw data in various forms and highly general mathematical statements. Nevertheless, geographers work on the premise that it is valid to draw some conclusions about the real world by drawing conclusions from a map of it, and that topographical maps are particularly appropriate for drawing such conclusions.

While cartographers strive to produce better maps, their criteria for success may be circumscribed by limitations in their approach and intentions, and in their knowledge of user's difficulties. As Wood[222] pointed out, the breakdown in communication may be because the user misuses, misunderstands, or mistakes the reliability of map information on the map, but solutions which require changes in the user, for example by instruction and training, may be less practical, though more desirable to the cartographer, than changes made by the cartographer to acknowledge and circumvent known limitations of communication in the user. Some of these problems of failure to communicate with the user are probably more recalcitrant with statistical maps (Jenks[479]) or thematic maps (Gerlach[480]) than with topographical maps (Birch[481]). Generally, the cartographer's intention to produce a clear map which looks both attractive and accurate leads to an intrinsic failure of communication when the map is based on information which is less clear and less accurate (Wright[16]). But it may be impractical to expect map users to remember that the map cannot tell the whole truth and that what is on the ground rather than what is on the map is significant, (Boggs[482]).

The cartographer's intentions are also a function of his willingness to adapt to technical innovations and knowledge of the user's requirements (Heath[147]). Semantic differential techniques might be effective in clarifying what the cartographer is trying to achieve, particularly if used in conjunction with user's comments on the efficiency of the product (Bartz[483]). Morrison[473] uses the terminology of set theory as an aid to specify the rules for developing sets of map symbols, but Keates[484] emphasised that the user must also know the basic rules about the graphic image which the cartographer is following. This implies that the map image itself must make these rules more self-evident to the user. Rules derived from research elsewhere may not be applicable to maps, and cartographic views of what constitutes legibility may not generalise (Bartz[99]). Principles of semiotics may be applicable to maps, but the choice of theories for studying the effectiveness of cartographic communications seems to reflect the cartographer's intentions more than the needs of the user. Despite the frequent references in the literature to the need for the cartographer's intentions to be related more closely to the needs of the user, in practice they seldom are, and even in relatively specialised areas such as aviation maps, cartographers have at best very vague ideas of how their products are actually used.

Sometimes the cartographer's intentions are stated in explanatory marginal notes or in the specification. But the latter is rarely read by the user and is written for the cartographer's benefit rather than the customer. Where the

intentions are stated, practical difficulties in implementing them have not always been resolved. One example is the intention, frequently stated in descriptions of topographic aeronautical charts, to portray relief in a way which meets the needs of many users to see at once the general nature of the terrain yet still derive more accurate and precise information on absolute and relative heights. Frequently, in relief portrayal there remains a distinction between what is needed and what has hitherto proved to be possible.

The literature on aviation maps also illustrates the cartographer's intention to meet what he interprets to be the needs of the user and his lack of complete success in doing so. New designs which it is argued will be more effective in meeting users' needs appear from time to time (Freer and Irwin[485]; Miller[123]; Sicking[486]; Randall[487]; Bennett et al.[114]). Rules and standards to be followed in cartographic practice are compiled (Anon[488]; Anon[489]; Adams[490]). Design proposals are formulated (Meine[491]) and the cartographer's intentions made explicit by interview techniques (McGrath[432]). However, some problems remain unresolved.

The cartographer seeks to select the most appropriate information and portray it effectively. In aviation, this entails a knowledge of tasks and environments which he rarely possesses. He also abhors empty space on a map, and therefore moderates his selection criteria according to the quantity of information which could be portrayed. A small scale map of a city may show a tiny proportion of the information which might be relevant to aviation, whereas a map of a desert region at the same scale might show everything there is to show, including transient insignificant features invisible from the air. Thus the cartographer does not succeed generally in conveying to the aviator how much he can expect to see, and particularly in indicating whether navigation by dead reckoning would be more appropriate than navigation by visual reference, because of the lack of visible landmarks. Detailed studies of the selection criteria used on topographic maps has been carried out by McGrath and Borden[121], and McGrath and Osterhoff[325].

The map may convey very little information to the user on how far the cartographer's intentions have been successfully realised. A vital feature for navigation may not appear on the map either because its importance was not recognised, or because there was no means of representing it within the conventions being employed, because although a feature has rarity value in one region, it is so common as to be valueless in other regions (e.g. minor roads, very low mounds, isolated trees, ditches), and therefore the whole class of features is omitted. Alternatively, a particular feature may be so common in a region that individual examples serve no useful purpose for navigation, and a more general coding is needed to show for example very numerous small villages, complete woodland coverage, extensive swamps, dunes etc. It is therefore necessary to find a means of reconciling the needs of the aviator for uniformity of selection with the need to modify that uniformity when its consequence is the proliferation of one particular symbol or feature to the point of unintelligibility and total lack of utility for navigation.

7b CARTOGRAPHY AS A LANGUAGE

Although cartography has sometimes been treated as a language, the introduction of new ideas into linguistics, particularly those of Chomsky[492], has led to considerable controversy on what a language is. If a map can be treated as a system of signs, isomorphic with the real world which they represent, then it may be legitimate to apply the general theory of signs, i.e. semiotics, to maps, and thus to explore the formal and logical aspects of the sign language of maps as a branch of linguistics.

Harvey[465], Dacey (cited by Harvey[465]) and Ratajski[467] have all considered the map as a formal language, with its three defining characteristics of semantic, syntactic, and pragmatic relations or dependencies. Semantic aspects of the map language cover the choice and physical properties of symbols, signs and conventions. They include the rules underlying that choice, which may become explicit if a new sign has to be formed, and they concern certain aspects of their psychological properties and interrelationships. The logical relationships between the map and the real world and the rules for formalising the meaning of each sign are also included. Syntactic aspects cover the kind of statements which maps can make, and the internal structure and limitations of such statements, such as the general inability in map language to state that something is absent as distinct from inferring it from the absence of a sign. Pragmatic aspects of the map as a language deal with the context in which it is used, and particularly with the relationship of its symbology to the cartographer and to the user.

Any set of signs must have semantic, syntactic and pragmatic characteristics before it can possess an inherent structure which permits the user to attribute meaning to it (Easterby[493]). However, approaches to display design may also be interpreted in terms of principles of perceptual structuring or multivariate information theory models, as well as in terms of language (Easterby[96]).

Analogies between maps and other concepts have been common: analogies between maps and language have been considered by Harvey[465], between maps and models by Board[461], between maps and theories by Toulmin[494], and between maps and thinking by Bartlett[87]. The propensity of many writters to refer to maps as illuminating relationships among other principles they are trying to grasp, has served to obscure rather than clarify what a map is and how it functions. Using a map as a kind of universal metaphor has absolved authors from thinking very clearly about the nature of maps and from trying to seek explanations of how they function as stores of cartographic data and as the medium for communicating cartographic information.

The notion that cartography may be considered as a language is by no means universally agreed. To Petchenik[495], maps and language are essentially incompatible, a theme developed more fully by Robinson and Petchenik[459]. Only if the notion of language is used so vaguely as to be nearly synonymous with communication may it be applicable to maps. Yet to consider cartography as a language is not an unorthodox approach, and the very existence of semiotics as a branch of linguistics suggests that parallels between maps and languages can be drawn. One question which arises is whether there is any value in doing so. Learning to read involves differentiating between graphic symbols and learning the code between the written word and speech sounds (Gibson[496]), and the process of learning to relate maps to aerial photographs has some analogies with language (Dale[497]).

In certain respects learning a map legend with its code between symbology and words has linguistic affinities, but non-standardised map symbols may be equivalent in some respects to a foreign language, in so far as they require the learning of a new code, some items of which may be deduced or interpolated. Dornbach[127] insisted, however, that a map must not be as difficult to comprehend as a foreign language. Ratajski[498], in his discussion of map language, noted that knowing a thousand words of a language would permit communication in it but knowing a thousand signs used on topographical maps does not lead to a comparable facility in communication, largely because of non-standardisation. He proposed a logical symbol classification which lent itself to progressive elaboration and sub categorising, to promote efficient communication through map language. A comparable approach by Morrison[473] also sought to specify a syntax for map symbology, based primarily on corresponding geographical data and representing visually imitative or equivalent symbols, mimetic rather than arbitrary changes in the parlance of Robinson and Petchenik[459].

It is salutary to note that many of the current misgivings about the linguistic properties of sets of map symbols, and many of the problems of cartographic communication, were stated long ago by Blaut[149]. He mentioned that maps must emphasise spatial and neglect temporal data, that some distributions cannot be clearly mapped, that the mapping of boundaries is frequently inadequate, that the map, being a two dimensional abstraction, cannot deal adequately with verticality or stratification, and that the map can suggest causal relationships which do not exist. Perhaps his most telling point is that each of the symbols employed on a map must be defined and explained in words, however complex the concept it represents.

Linguistic concepts may not seem directly applicable to the map as a visual product, because they seem inadequate for dealing with specificity of location, with spatial relationships and with regions where the absence of information on the map is highly meaningful. The direct application of linguistic concepts to a map may also be inadequate for suggesting the kinds of error which will be made when it is used. But language has a clear role in cartography in that what appears on any map is ultimately dependent on the language used in surveying, in defining the specification, and during compilation. In this sense, maps differ fundamentally from photographs and many other forms of visual images because these have no inherent vocabulary (Langer[499]; Ivins[500]). Yet every symbol on a map can be expressed in terms of verbal language, and is so expressed in the map legend and in the map specification. While there is no immediate verbal equivalent to state the spatial relationships between map symbols, there is a choice of language for doing so, in terms of headings and distances, of grid references, or of measures of the map surface itself. Verbal descriptions of spatial relationships between symbols can be used to enable a map position to be located with a degree of accuracy and specificity comparable to that obtained by using grid references (Taylor and Hopkin[151]).

The distinction drawn by Robinson and Petchenik[459] between mimetic and arbitrary depiction refers to a continum or dimension of the degree of visual equivalence between the map symbol and what it represents. Mimetic symbols are to some extent visually imitative, not entirely dependent on verbal language for their meaning, and partly pictorial. Certain mimetic qualities may be present where a symbol has no visual equivalent to what it represents. Differences in size, opaqueness or colour saturation, for instance, may have some correspondence with differences in what the symbols represent: size of type face in the name of a city may be associated with the population size of the city. The use of mimetic principles is common in cartography, but to be successful the correct cartographic and symbolic dimensions must be chosen. The number of visual intervals must not be so numerous as to render them indiscriminable, and the requirements of visual balance must not be violated.

Mimetic principles may also be a source of particular kinds of error. Errors may occur because the intended meanings are not sufficiently self-evident, or are mistakenly associated with other dimensions. Differences in magnitudes may be assumed to correspond more closely to the mimetic symbology representing them than is intended. Two or more mimetic dimensions may be combined in a way which violates the mimetic principles of intelligibility. However, the use of arbitrary symbols as an alternative to mimetic ones imposes errors of its own type, and leads to such major problems in map learning and interpretation that it can only be contemplated for a limited number of symbols. Usually, mimetic symbols, though possessing some visual meaning, have to rely on verbal language to define their usage and the boundaries between them. The meaning of each symbol can be expressed precisely in words, and indeed is so defined. The successful use of mimetic symbols requires some knowledge of whether the intended meanings will be associated with the chosen dimensions, whether these refer to shapes (Koponen et al.[29]), to colour (Van Der Weiden and Ormeling[501]), or to the relation between colour and shapes (Keates[502]).

Many of the problems of the relationship between language and cartography are centred on the role of the map as a representation of things in space. The advent of computer applications to cartography, and of computer-drawn maps, implies that maps in principle may be specified in a computer language, the limitations being the practical ones of the very large number of instructions required and the large information storage capacity, rather than any matter of principle.

This means that all the information which a map contains can also be contained in the alternative form of a computer program. Whether cartography is a language then becomes enmeshed in the alternative debate about whether computer programming languages are true languages or not. It may be argued that this is treating a map purely as an information store, but the distinction between it and a computer store then becomes one primarily of accessibility, and progressively more elaborate computer peripherals and display technology may gradually blur this distinction too. Some of the ways in which such traditional distinctions are vanishing can be traced in the applications of computer technology to the graphic arts, and to animation in particular.

In aviation, the question of the relationship between cartography and language is particularly important. It is a common requirement to convey topographic information verbally between remotely located users. Map information must therefore be compatible with verbal language. One possible criterion for judging the efficacy of certain aviation maps is to ascertain the facility with which their contents can be expressed and conveyed to others verbally, both quickly and without ambiguity. Maps have to facilitate the correct strategy and choice of map features in verbal communications. What cannot be expressed verbally is no use for such a task. Nor is information which may be visible to all concerned, such as field patterns, but which the map fails to depict. It is necessary to know the entire contents of the map legend, and the principles of its compilation, before the user can speculate on what a blank space on the map might contain. When he does so, he has to express his speculations in his own verbal terms, but these verbalisations nevertheless have to remain compatible with the visual map content, and be interpreted in relation to it.

7c THE MAP AS A PRODUCT OF CARTOGRAPHIC LANGUAGE

Since there is no agreement on whether or how far cartography may be considered as a language, there cannot be agreement on the extent to which the map is a product of cartographic language. It is possible however to assess the influence of cartographic conventions on the visual forms used to convey map information, and on their efficiency. In particular the limitations on communication which may be traced to this source can be specified.

Cartographic principles encourage an elemental or dissecting approach exemplified for example by Dahlberg[150] and by Heath[147]. Attempts have been made to use a cartographic syntax to derive sets of symbols which reflect the distinctions and similarities in meaning which they are intended to represent (Morrison[473]). Nevertheless differences in meaning are invariably conveyed by discrete differences in the visual characteristics of the symbols. Even a continuum may have to be prescribed by a small finite set of mimetic symbols varying according to one or more visual dimensions, where the limited number in the set entails some approximation and inaccuracy and where the boundary between consecutive symbols in a set may be arbitrary in cartographic terms, being dependent on survey data, or on quite independent information. For example, the size of type face for the name of a city will simply denote a band within which the population falls: it does not depend directly on its geographical importance, its visual appearance, its physical area, or other topographical features of practical concern in cartography or in aviation.

Cartographic language condenses an infinite diversity of information into a limited number of defined information categories, in order to render the information intelligible and meaningful. Frequently, existing data collection practices rather than the changing requirements of users define the categories employed. This is partly due to the long response times involved in meeting a new user requirement. Whilst some users might appreciate an elaboration of certain categories, the data required may not be readily available and may need to be surveyed. Structural distinctions between bridges, detailed power line patterns, and the depiction of individual, prominent trees are examples of features which could be useful for navigation or flight safety purposes but which are not normally portrayed on air maps because of difficulties in data collection. Other categories might need the development of a suitable set of symbols: the positive identification of a railway station in use might be much helped by an indication of the extensiveness of railway buildings and the number and length of platforms. Some limited information might even be incorporated within existing symbols.

It was contended by Dornbach[127] that the cartographer is mainly responsible for adhering to standards and conventions which perpetuate the notion that a map can be useful only if its language has been learned and understood. Whereas the cartographer may reasonably uphold that others outside his profession who would impose imitative symbology upon him fail to appreciate the subtlety and complexity of cartographic meanings which existing symbology conveys, this attitude does imply that some reform may rightfully be expected from the cartographers themselves whenever there is evidence that the existing symbology fails to convey its meaning correctly or that new or different information which the map does not provide is needed by the user. To be fair, cartography has been much preoccupied of late with heart searchings about what maps are for, why they take the form they do, how they may be improved and what their nature as a medium of communication is. So far this introspection has led to much questioning but few answers. The introduction of technical display innovations to aviation cartography has stimulated the quest for a logical cartographic language. It has also made the problems more interdisciplinary so that it is not only cartographers who are questioning the visual conventions used on maps, but it is also display scientists, engineers, and ergonomicists who are less willing to accept cartographic tradition as the only source of solutions to map design problems.

Traditional cartographic language contains symbols which vary greatly in their pictorial or mimetic qualities. While this in itself may be desirable and advantageous, the logic seems poor for deciding how pictorial the set of symbols for a given information category need be. Airports may have aircraft symbols or runways but railways never show trains. Distinctive vertical features such as power transmission lines employ the pictorial symbol of pylons, but lay them flat.

Successive height bands may employ a set of hypsometric tints which bear little pictorial resemblance to the colour of the ground from the air, while the convention of hill shading which has some ostensible pictorial relevance negates this by portraying shaded regions as if the sun were in the North West, in the northern hemisphere.

While the method of portrayal of certain information categories on the map may seem to be a product of cartographic language to the extent of being unnecessarily illogical and obscure, the compatibility of different information sources may pose problems which are more difficult to resolve, particularly when the different sources are interdependent. A topographical aviation map typically shows height by means of contours, hypsometric tints, hill shading, spot heights and maximum elevation figures. These, individually or collectively, invariably fail to convey the shape of the landscape in any way which permits immediate visual recognition. They remain largely visually separate, to be integrated where necessary by visual search, comparison, interpolation and deduction. After protracted learning and experience, it is possible to deduce the visual appearance of the terrain from the map information provided, and to do so quickly. But it is not possible to do so without effort and error, by an immediate visual structuring of the data, as it is with many artistic landscape drawings. To achieve this implies more than merely modifying existing cartographic conventions. Radical revisions in techniques are probably necessary, including the abandonment of some conventions and the introduction of others, perhaps with repercussions for printing and ink technology and other production processes.

When the decision is taken to portray a cartographic dimension by a set of symbols, two kinds of question arise. One concerns the number of symbols which there should be in the set, and the definition of each so that the demarcation between them is clear and no ambiguity can arise about which should be chosen in any given instance. The other question concerns the visual form each symbol should take so that symbols should on the one hand be sufficiently alike to show that they are related and belong to a single set, and on the other hand be sufficiently different to be visually discriminable, since the point of differentiating between them is lost if they cannot readily be told apart. Commonly one coding dimension such as colour may be used to convey meaning and membership of a set (cognitive coding), and another such as size or shape differentiate within the set (disjunctive coding). This latter problem lends itself to simple experimentation, and although, as Robinson and Petchenik[459] note, much of this has been done on simple forms in psychological experiments with no intended direct relevance to cartography, certain studies have been conducted on aspects of map symbols (e.g. Ekman and Junge[180]; Wright[181]; Flannery[182]) though mainly concerned with symbols for statistical or thematic rather than topographic maps.

A subtler influence of cartographic conventions on the map is the concept of visual balance whereby the information on the map should be portrayed in a form which reflects its relative importance without assigning any category of information undue prominence, without obscuring any other category and without causing visual clutter. The appearance of a map is a product of its balance. The concept of visual balance requires that the relations between the contents should be evenly perceived by virtue of their visual prominence, and this restricts the range of sizes, contrasts, saturations and brightnesses within which the information must be portrayed.

Many writers on maps note that a concept which differentiates maps from other information displays or information storage systems is that of structure (Robinson and Petchenik[459]). The concept is however used vaguely, to denote the correlation between the portrayed features on the map and what they represent, and is not always carefully differentiated from numerous other sources of information which, though not maps, possess an apparently comparable structure, and which range from satellite photographs to circuit diagrams. Certainly, the communication of pattern and structure in the real world is a fundamental objective of the cartographic language. Detailed knowledge on how this is best achieved is sadly lacking. Cartography generally suffers from a paucity of concepts, terms and definitions in relation to its portrayal of relationships, pattern and structure. Information theory analyses of map content have produced a number of interesting comparisons between the content of maps at different scales (e.g. Sukhov[475]) and between maps and other graphic displays, such as written texts, but their value is largely determined by the extent to which they measure structural expectancies.

Cartographic language affects the sources of error or misinterpretation in the portrayed information, and the levels of accuracy which may be achieved. Even if a point source of information has been accurately surveyed, and could be accurately positioned, the method of portrayal may degrade the potential accuracy, or lead to some ambiguity. The exact locations of obstructions and power transmission lines may not be immediately obvious from the symbols shown on the map because they may need to be distinguished from other symbols by shape coding (e.g. wavy lines) that introduces ambiguity over the precise position of the feature. Imhof[158] discusses one form of cartographic information where there is considerable freedom in placement on the map, the positioning of place names. He contended that there is a definable optimum position for placing each name, and rightly commented that the problem of placing names had not received the attention warranted by its importance. However, the implication that it is generally feasible to place the name and that there is room for it, tends to avoid the more fundamental problem that the clutter of names can become self-defeating and that in certain regions there may not be room for some names. The choice of symbols also determines errors of interpretation which may be made. Some of these occur when quite disparate and unrelated classes of cartographic information are insufficiently differentiated in visual terms, so that for example a footpath may be mistaken for a local political boundary. Other errors occur because subdivisions within a category of information remain too similar in their method of portrayal or have no logical relationship to the distinction being drawn. Still further errors occur if too large a range of visual prominences has been used within the map so that certain symbols for less significant information may be difficult to discern amid more prominently portrayed features.

A primary function of maps is to indicate the location of the cartographic information symbolised on the map. Cartographic language or symbology introduce certain further distortions in positional information because of limitations on the space available on a map of a given scale. Many linear symbols occupy an area far broader or larger than the feature they represent. Some positional distortion is inevitable for instance, when several linear features are adjacent in a narrow valley or along a coastline. Many valleys contain a river, one or more main roads, a railway and housing within a small valley width, and cannot be separately portrayed without exaggerating the width of the valley. Physical proximity is incompatible with accurate mapping of numerous adjacent features.

Only a limited number of distinct symbols can be employed for any information category, and sometimes only one symbol can be used such as lines for portraying linear features. This often means that for most features only those salient characteristics which determine its classification can influence the way it is portrayed on the map. Roads may be classified according to the number of lanes or types of surface, but these classifications may prevent further distinctions being drawn, say in terms of road speed. Each symbol functions by classifying together those features on the map which possess a pre-defined characateristic in common (Keates[484]). Different features depicted by the same symbol have their similiarity exaggerated. Similar features depicted by different symbols have their differences exaggerated. The choice of symbology is therefore bound to be in some respects misleading. It may, for instance, differentiate between used and disused railway stations, which are identical as features but merely differ in usage, yet use the same symbol for railway stations in use which have gross differences in their size and appearance. Some confusions are therefore the inevitable concomitants of the limitations of cartographic symbology and language. Limited numbers of symbols can only reflect gross differences and not subtle ones, and the boundaries between symbols may be apparently arbitrary.

Empty space on a map is used by the cartographer to convey cartographic information. The absence of symbols may be used to indicate that certain features are present, but that they are so common as to convey little useful information for navigation purposes, as in areas of general forestation. Empty space is used to increase the visual prominence of important information. This occurs in the case of boxed spot heights, where topographical information has been cleared from within the boxes. In the more general case, information is omitted in order to reduce clutter and ensure that the user's attention is attracted to the important information. Little or no cartographic information may be intended to indicate to the aviator that he should concentrate on dead reckoning procedures rather than visual referencing and map reading because the suitable ground features are not available or because the relief information is not reliable. Empty space may also be an integral part of the symbology, such as in the case of linear features where they pass under bridges and through tunnels.

Such constraints become particularly apparent when the question is asked, what do users of aviation maps need to know. They may need to know the shape of cities viewed from the air to identify them positively. But such a task may require parts of cities densely packed with buildings and devoid of greenery and open spaces to be distinguished from leafy suburbia which may not look like part of a city at all from the air. The military pilot may need to know and recognise targets of military significance, but there is no such cartographic category and no equivalent to this concept in cartographic language.

7d MAP READING BY THE USER

In information flow models of cartographic communication, the process of construction of the graphic image is followed by the acquisition of information from the map by the user, through visual scanning and map reading. The user's interpretation of information obtained from the map and its effect on his perception of reality and his subsequent behaviour may be considered as later, more advanced stages of cartographic information processing.

Many of the factors pertinent to map reading, discussed in preceding chapters, determine its success and limit the subsequent interpretations made by the user. These range from the fundamental components of the visual process, involved in the detection, discrimination, recognition and identification of information, through the complex roles of visual search, attention, memory, visual imagery and expectancy, to the general influences of individual differences, training, motivation, operational requirements and map tasks. Environmental factors such as workspace, illumination, and vibration, and time constraints imposed by high workload and the duration of flight, place additional practical limitations on the user's ability to gather information from the map. In his model of the process, Kolacny[463] lists the following inputs during map reading in addition to information obtained directly from the map:

(1) Needs, interests, aims.
(2) Knowledge, experience.
(3) Abilities and properties.
(4) Psychological processes.
(5) External conditions.

The sources of inputs identified by Kolacny may overlap somewhat but the important point is that the model recognises that other information in addition to that obtained directly from the map, is involved in map reading.

At a fundamental level, map reading can be treated as a decoding process in which visual signals are transformed into meaningful cartographic information, according to the principles of cartographic language. The success with which this

simple transformation from visual signal to cartographic meaning is achieved can be tested across sets of symbols by the analytical procedures of information theory (Taylor[111]). Koponen et al.[29] studied the meanings evoked by different map symbols and classified them according to their "association value". Numerous psychophysical studies of responses to symbols scaling quantitative statistical dimensions on thematic maps adopt a similar approach.

In practice, map reading frequently involves more than the mere association of meanings to symbols, particularly with experienced map users. Physiological and attentional factors may tend to restrict the assimilation of information during map reading to discrete, sequential sampling, in a serial rather than parallel fashion, rather like reading written text. Yet, information can be obtained from peripheral as well as central vision during search, and features on the map can be processed as groups or clusters rather than as individual elements. Furthermore, by utilising memory for short and long term storage, the observer can build up and visualise a complex mental image of whole areas of the map, of patterns, interrelationships, and dependencies on the map outside the immediately sensed. The success of this process goes beyond the ability of the user to utilise the map legend, and draws on his training and past experience with maps, on his knowledge of cartographic language and of the principles used to compile the map content, and on his understanding of the practical constraints of the map making process. Clearly, map reading is an active rather than a passive process, involving inputs from the observer as well as from the map, and analysis-by-synthesis rather than simple stimulus-response associations.

Inputs to the map reading process generated by the experienced observer are likely to facilitate performance, particularly when inductive reasoning is involved, such as when deciding what is meant by "empty space" on the map. On the other hand, observer inputs may be inappropriate and reduce the efficiency of information transmission, such as when using a new map, compiled and coded by principles different from those used on conventional maps. Such inputs may cause identification errors and confusions between the meaning of different symbols. Information theory treats this as system "noise" and provides a method for quantifying the amount of noise in the communication channel, which can be incorporated in a general measure of the efficiency of information transmission. Taylor[111] has demonstrated how information theory analysis of map efficiency, by taking account of system noise, may be more sensitive to differences in map design than more traditional methods of scoring map reading performance.

The emphasis on individual symbols and on measurable responses to them in cartography was criticised by McCleary[503], who noted that studies had neglected the total process of map reading in favour of its constitutent parts, with the result that few quantitative measures could be applied to the total map reading process. Robinson and Petchenik[459] use a similar argument to express doubts about the validity of using theory developed for uni-dimensional phenomena. Whilst excepting these limitations, Board and Taylor[458] argue that symbol-response analyses of map reading should be used in conjunction with more realistic map reading tasks to identify possible sources of symbol identification errors that might otherwise be difficult to detect by more gross measures of performance.

Most studies of map reading give the user specific tasks to do, and assess how well he does them. This is done primarily by measuring the speed and accuracy or errors of his responses. Christner and Ray[103], for instance, used identifying, locating, comparing, counting and verifying tasks. They found that intercorrelations between these tasks could be explained in terms of three factors: recognition, search, and remembering. Phillips et al.[267] studied the legibility of relief maps using thirteen different tasks. Cluster analysis produced three groups of tasks with high intercorrelations; tasks involving judgments of absolute elevation, tasks requiring judgments of relative elevation and tasks requiring visualisation. Alternatively, the observer may be asked to describe how he set about the map reading task, and eye movement records may be taken to provide supplementary data on the number, duration and sequence of fixations which may be related to map content. The precision with which this can be achieved will depend on the method of eye movement recording and on the importance of peripheral cues.

It is quite rare to try to measure what people do when given a map without specific instructions on what to employ it for. Yet many people read maps with an attention approaching compulsion, to the extent that those who conduct experiments on map reading learn that it may be difficult to keep the subject's undivided attention while giving him his instructions if he has a map before him which is drawing his attention. This property of maps, reflecting the attractiveness and attention-getting qualities of some of the display principles which they incorporate, has not received systematic study. People tend to look at a map for much longer than at other forms of non-dynamic display conveying information. It would be useful to know what people look at and what they can recall, in the absence of firm instructions. It would be expected, in view of the time spent looking at the map, that subjects could recollect a considerable amount of detail afterwards, but whether their recollections would match the cartographer's intentions is doubtful.

Commonly, cartographers assume a sophistication in the map reader comparable to their own, but the reader can seldom appreciate or even notice many of the nuances of meaning which the cartographer has been at pains to depict. Thorough instruction for the map user, plus the employment of cartographic techniques to make the meaning of maps as clear, unambiguous and obvious as possible, are necessary if the cartographer's intentions are ever to be realised. It is futile to portray distinctions which are never noticed, are not understood, or have no practical utility for the user. It is too narrow to view the function of maps only in relation to highly specific tasks, for which every item of portrayed information may be classed as relevant or not, when maps are also used more informally and unsystematically, to satisfy curiosity because they are intriguing and to accumulate knowledge of maps, map-making and map-makers. The user of any map has a frame of reference which includes other maps, and which he uses to make judgments about factors such as scale and information density.

Keates[484] suggested that discussing user's general requirements will not be enough to guarantee easier map reading, and that it is necessary for the user to share with the cartographer the same rules for interpreting the graphic image. This implies that the cartographer must try and make the structure of the map more explicit for the user, and be more concerned with the process of communicating to him (Molineux[477]). The needs of the user, when described, are not customarily expressed in cartographic terms, but in terms of the tasks to be done and the speed and accuracy required in doing them, or in terms of general visual concepts such as clarity, legibility, and freedom from clutter. Miller[11] noted the requirement for rapid accurate map reading during flight, and Chichester[17] indicated the need to omit everything not essential for the tasks. Similar recommendations continue to appear, but they refer to what should be achieved rather than show how to achieve it.

Although discussions of the needs of the user and the study of psychological principles both contribute towards effective cartographic communication, they cannot in themselves provide it. To identify the needs of the map user does not guarantee that it is feasible to meet them. To demonstrate what is psychologically discriminable does not imply that an intelligible meaning can be assigned logically to each symbol and subsequently remembered. Studies of users' needs on the one hand, and of symbology on the other, provide a framework within which solutions might be devised, but do not themselves constitute a solution. Defining the stages in the process of cartographic communication encourages studies on each stage without checking that the findings are matched or compatible, and also encourages examination of the stages which lend themselves most readily to experimentation rather than those which pose the most difficult communication problems. The tasks of deducing from the user's requirements what information should be shown, and of deducing from psychophysical studies how it should be portrayed, remain to be done, and above all these tasks have to be reconciled. There is very often an implicit assumption in cartography in general, and in aviation cartography in particular, that all things are possible and that there must be a satisfactory solution to every communication problem. Yet it may not be so.

Studies relating design variables to map user performance (Wheaton et al.[504]; Olson[505]; etc.) tend to discover relationships rather than provide explanations for them. Studies on those who use aeronautical maps (Lancaster[506]), on the relationship between users requirements and standard cartographic products (Bard[365]), on how user requirements should be identified (Cummins[328]), on methods for developing design criteria for maps (McGrath and Borden), on how existing maps might be improved (Anon[507]), on the impact of automation on aviation-map production (Misulia[372]) and on manual or automated navigation (Lewis and Anderson[354]) – all seem to imply that a study of the processes involved is bound to lead to an operationally acceptable solution. But some problems – reading a topographical map at night while wearing image intensification goggles, or using a topographical map at high speed and low level in conjunction with a side scan radar display – may not have a cartographic solution which will permit acceptable levels of operational performance to be achieved. Other problems – devising a map specification for numerous operational roles without generating excessive clutter, or depicting extensive woodland without significantly obscuring relief information over which woodland symbology is superimposed – may not lend themselves to an ideal or optimum solution, but be a matter of effecting a compromise which is just acceptable to all or most users but fully satisfactory to none.

Attempts to study more directly what the user does while reading a map may also be descriptive rather than explanatory. Eye movement recording may show, with a variety of degrees of accuracy depending on the technique employed, where the user is looking on the map surface but may fail to indicate whether he is attending to what he sees, whether he can understand it or whether his interpretation is correct and corresponds with the cartographer's intentions. Nor can eye movement recording indicate how much peripheral vision is being employed, or how far Gestalt principles of visual structuring and imposition of meaning are contributing towards the user's understanding of the map as a whole, although design decisions greatly mar or facilitate such visual structuring processes. It is difficult however to measure in quantitative behavioural terms the immediacy and success of coherent visual structuring of the map, as distinct from obtaining subjective reports about it. It is commonly assumed to be advantageous if the map design encourages immediate visual structuring in ways which replicate faithfully what is mapped, particularly in the depiction of terrain, but measures to ascertain how effectively this has been achieved, or whether it is worth achieving, have hitherto proved elusive, and may remain so. It may be argued that the responsbility for deficiencies in such structuring rests with the compiler who should learn more about principles of design and their application (Balasubramanyan[254]). It may also be argued that map users need to learn much more about how to read a map since maps are generally functionally efficient if properly used (Wood[227]). Studies on single aspects of terrain depiction, such as that of Kempf and Poock[508], therefore have to be interpreted in the general context of the map reading relief. The emphasis of experimental work on single parameters, mainly psychophysical, has tended to carry the false implication that such factors are the main determinants of how a map is read and how efficienctly it is used, yet such factors may be less important than subjective cues such as expectancy (Bartz[507]) or than general attributes of the map as a whole such as characteristic perceptual structuring (Robinson and Petchenik[459]).

The concept of map reading can itself be misleading, implying as it does a closer affinity between a map and a written text than between a map and a photograph or picture. Just as in the written text current studies tend to emphasise words, their sequence, their interrelationships and their structuring into phrases and sentences rather than the theme of the whole text, so with maps the emphasis is on specific symbols, shapes and colours, on their juxtapositioning, their specific meanings and interactions rather than on the theme of the whole map. Therefore in studying map reading more attention needs to be paid to the whole process than to its minutiae.

7e THE USER'S INTERPRETATION

The previous section on map reading was largely concerned with the acquisition of information from the map and the transformation of visual stimuli into meaningful cartographic information. It was noted that this was an active rather than passive process influenced by factors such as the motivation, interests, expectancies, experience and training of the observer. To this extent, it can be argued, that the assimilation of information from the map is an interpretative process in which the map is not accepted as given; rather, the contents are sorted, filtered and selected according to the observer's notions of their relevance to his task. These same psychological factors are more clearly relevant to the complex decision making that follows information acquisition from the map, leading to such diverse outcomes as the search for more information, deductive reasoning, the formation of opinions and attitudes, intellectual judgments, revisions of geographical schema and orientation, altered perceptions of reality, and modifications of behaviour.

A major methodological difficulty in studying this aspect of cartographic communication is that of measurement. The user's interpretations, his geographical schema, and his perceptions of reality are by definition subjective. Consequently, investigations of factors affecting map interpretation are constrained by the difficulties associated with the reliability and validity of subjective data.

The extensive literature on mental maps, cognitive maps, and images of the geographical environment is not of great practical help in furthering understanding of how users interpret maps, and indeed was not written for that purpose. Tolman's[85] original work on cognitive maps, based on maze learning studies, was interpreted in terms of the learning theories in vogue at the time but now out of fashion. Griffin[88] also emphasised learning theory, and noted that maps which can be reconciled most readily with the distortions of existing mental maps will be preferred as guides to orientation. He anticipated much later work by noting that topographical mental concepts reflect user's interpretations based on the relative importance of items to him, rather than reflect geographical reality. Subsequently the meaning of the notion of cognitive mapping has been extended in accordance with the grander and more amorphous role assigned to cognition in psychology (Kaplan[510]), and although it is still often employed to refer to the acquisition, storage, collation and use of information about the spatial environment, it may also refer to a broad class of psychological adaptive processes (Downs and Stea[511]). Where a geographical connection is retained, mental maps may refer to notional references for places or to knowledge of location (Gould and White[82]). Though of interest in their own right, and as an indication of the widespread ignorance of the geographical whereabouts of features with familiar names, studies of mental maps cover only a small part of the topic of the user's interpretation of maps, by illustrating the source of one kind of misinterpretation – not knowing where to look or looking in the wrong place because of misleading preconceptions.

The map user, in a variety of roles, has to make decisions based on information obtained from the map. Maps share with other displays the characteristic that one measure of their effectiveness is the quality of decisions based upon the information they contain (Silver et al.[512]; Landis et al.[513]). Yet this kind of influence goes beyond those normally discussed when the needs of the map user are considered. More commonly, the user's interpretations are deduced from studies involving performance measurement on tasks with maps such as navigation and geographic orientation (e.g. Osterhoff et al.[320]), as reported in Chapter 3c, on route selection tasks (e.g. Morrison[514]), on relief interpretation tasks (e.g. Phillips et al.[267]), and on various map tasks in the field (e.g. Berry and Horowitz[515]; Wheaton et al.[504]; Hill[516]).

When a user looks at a map, his interpretation and subsequent decision making may be expected to be influenced by several factors. It depends on his motivation – why he is looking at the map and what he is looking at it for. It depends on his existing knowledge and on what may be termed his geographical frame of reference, that is, his prior knowledge about the region depicted on the map and about adjacent regions, his understanding of cartographic technology, and his knowledge of assignment of meaning to the cartographic conventions that the map employs. His interpretation is a function of the map content and coding, the selection of information for portrayal on the map and of the visual means of portrayal, both in terms of specific cartographic information categories, and in terms of relative visual prominence and visual balance.

The user will interpret what he sees according to the estimated trustworthiness and accuracy of the information on the map. His interpretation is also affected by other sources of information about the particular region, route or target, whether these further sources are given in advance in the form of briefing material, instructions, explanations, or photographic or other collateral material, given concurrently in the form of exterior terrain views, radar map matching, or continuously generated collateral material, or given subsequently in the form of debriefing, evaluative analysis, archive material, or reinterpretation of the map and its associative material in the light of additional evidence. Finally the user's interpretation is affected by individual differences among users in their training, skills, abilities and understanding of missions and maps; inexperienced aircrew may know as much as experienced ones, but be less effective in applying their knowledge.

It would be expected that the user's interpretation of a map varies with familiarity with the map itself and with the terrain it depicts. Presumably it is possible to become so familiar with a geographical region that for many aviation purposes a map of it is no longer needed. Presumably it is also possible to become so familiar with a map that its usage is restricted to tasks such as measurement and plotting since it is no longer necessary to consult it to acquire a general appreciation of the terrain it depicts. These are presumptions rather than facts because quantitative evidence on how map usage changes with familiarity is lacking. While the validity of certain aspects of aircrew training associated with

91

their progressive familiarity with the training region is acknowledged, how this familiarity changes the usage and interpretation of maps has not been studied in a systematic manner.

Most map users have preconceptions or expectancies which influence where they look on a map, what they look for and how they interpret what they see. The precise effects of these preconceptions remain obscure because of a lack of data about what people do when scanning a map, and how their behaviour is changed by factors such as familiarity or changes in required tasks. Preconceptions have several implications, including a tendency for existing misinterpretations of the map to be reinforced rather than corrected, and a proclivity to omit certain stages of map reading which familiarity would make redundant.

The user's interpretation may betray his ignorance of cartographic production methods. In particular, he may interpret the positioning and nature of symbols with a literalness and accuracy which they do not possess. The user seems reluctant to concede when looking at a map that he is using a product which is man-made and therefore fallible. Although errors on maps are not common, and gross errors may be very rare indeed, nevertheless a few may escape the most rigorous checking. Errors may arise too because of the non-linear relationship between how much is portrayed on the map and what is available for portrayal. The user gradually learns that in some maps featureless landscapes are not shown as such, and that a blank space on a map may not correspond to an absence of features on the ground. But such learning occurs through experience and training, and is bound to involve some errors of interpretation during the learning process. Education and training of users may help to produce correct interpretations, and on some maps it may be fair to claim, as Wood[227] does, that cartographers, having taken great care and effort, have made a product which is an effective communication medium, so that the onus for improved reliability of interpretation must now be passed to the user. However, in so far as the propensity of the user will be to make, sooner or later, every mistake in interpretation that can possibly be made, it would not be prudent to rely too much on the user to avoid misinterpretations. While a knowledge of the principles of perception and of graphic design can assist map interpretation (Heath[147]), it is not in itself a guarantee against errors of interpretation, which depend rather on how successfully the knowledge has been applied. The problem of the continued reinforcement of an initially wrong interpretation (Lichte et al.[56]) may still remain.

Positioning of symbols, and more commonly coding, is used on maps to indicate the cartographer's conceptions of the relevance of the information to the user's task. On aeronautical charts, greater emphasis tends to be given to features that are visually prominent on the ground or that constitute hazards or obstructions. Thus, information on importance and relevance is not explicitly stated on the map and it is open to interpretation by the user. The degree to which importance can be conveyed to the user, say by colour coding or assignment to visual levels (Keates[120]), has not been examined empirically except in simple studies of figure-ground relationships (e.g. Dent[228]).

The perception and visual correlation of distribution of data on thematic maps has been studied by several authors (e.g. McCarthy and Salisbury[517]). This is a highly interpretive task, but it is not immediately obvious to what aspects of topographical map reading the results of this work are applicable. A study by Olson[518] found that the accuracy with which maps convey visual correlation is partly a function of class interval system and of the measures and experimental designs employed. Olson used computer generated sets of data of choropleth rather than isopleth mapping to study the relationship between mathematical correlation and subjective interpretations of degree of correlation between maps. The advent of automated drawing techniques, with their associated facility to produce numerous graphically complex symbols (e.g. "windrose" symbols) for quantitative data necessitating interpretation by the user, raises the issue of the user's ability to interpret such symbols in relation to other cartographic information on the base map. Rhind et al.[519] conducted some preliminary experiments on this theme and commented that the cartographer's preoccupation with accuracy in map production rather than in map use has led to vagueness over what constitutes an acceptable level of accuracy among users in their interpretation of map symbols. The computer generation of symbols must take account of known systematic distortions introduced by users in interpreting symbols. For example, users do not interpret the magnitude of circles in proportion to their area, and it is necessary to use an apparent size scale to achieve this effect if it is required (Flannery[182]). Many of the illusory perceptual effects which occur as part of the users' interpretation of such map features as isopleths, choropleths, dot symbols, and proportional symbols have been discussed by Clarke[255].

In practice, map interpretation by users of aviation maps often has to be done quickly, and the penalties for misinterpretation are high. The consequences of these factors for how and when maps are used, for the kinds of interpretation which occur as a result of haste or the serious consequences of error, and for map design have not received the detailed study which their importance warrants. Much emphasis is placed on the need for quick, accurate and error free map reading and aviation maps may tend to be judged by users by the extent to which they achieve these aims. Nevertheless, the need for speed in use is bound to be a source of misinterpretation, and the extent to which errors can be prevented by map design is of practical concern. It may be that in certain circumstances speed in map use does more harm than good, such as under conditions of geographic disorientation when the observer is unaware that he has departed from his planned track.

Maps are often used with collateral material and the user's interpretation of the map can be much influenced by the compatibility of the map with this material. Pattern matching, whether superimposed or side-by-side, is a highly interpretative task, particularly if either or both patterns include a great deal of superfluous and redundant information. A feature prominent on one pattern is often assumed to be prominent, or at least present, in the other. Errors of interpreta-

tion may occur when the feature is not present or when it has to be depicted in an unfamiliar form to give sufficient commonality of pattern to permit the matching task to be done at all. Invariably the map has to be modified for matching, particularly when the collateral information is a sensor display which cannot be manipulated. Changes to map content may be desirable and it may be necessary to revise drastically the visual organisation of the portrayed cartographic information to emphasise more strongly the salient features required for matching, in accordance with the general principle of giving greatest visual emphasis to information that is most important for each task.

Although it is self-evident that relevant abilities, training and experience in an individual user must facilitate his ability to interpret a map, it would be rash to make sweeping generalisations to that effect, and to assume that improvements in interpretation could be guaranteed by foreknowledge and by the provision, in advance or concurrently, of suitable collateral material. Welch and McKechnie[436] conducted an experiment on side-scan radar imagery, in which various levels of briefing failed to improve success rates or speeds in detecting five categories of operationally significant targets, compared with performance with no briefing, but they concluded that new and more adequate briefing techniques were probably needed, rather than that briefing would be pointless. Experiments by Olson[505], using simpler perceptual material, demonstrated the efficacy of training in the interpretation of map symbology, and also brought out the indirect benefit of training, namely clarifying the nature of the task and thereby improving performance at it. How far the user's interpretation of aviation maps would be improved, in various roles, simply by more or different training is not known. Nor is it clear which aspects of map usage have to be faithfully simulated during training to ensure adequate transfer of training to operational conditions.

7f THE VERBAL TRANSMISSION OF CARTOGRAPHIC INFORMATION

In aviation, and in other contexts too, cartographic information is communicated both visually and verbally. The original specification of the map is normally expressed verbally, the meaning of each symbol is expressed in words in the key or map legend, and the user often assigns meaning to the symbology by expressing it in verbal rather than visual terms. Cartographic information stored in memory may be coded visually, verbally or by both methods, depending on the individual's preferred mode of thinking. Whereas the cartographic literature often assumes that the cartographic communication process has been completed when the map information has been conveyed to the user, in aviation this is often followed by a further communication process in which the user conveys his interpretation of the cartographic information verbally to someone else. The effectiveness of the total communication process may therefore depend greatly on the facility with which information on the map can be verbalised. This implies that each symbol with a separate meaning should have a distinct verbal description or label as well as a visually discriminable form. It also points to the need for a generally acceptable vocabulary to describe the spatial relationships, patterns and structures typical of cartographic information which can be understood by someone else who may or may not be looking at the map when listening to the description.

Some information is coded in a verbal form in maps, such as place names and spot heights, or represented in a form which is readily verbalised, such as the grid system. The positioning of this verbal information on the map in relation to the topographical feature to which it refers may be quite flexible, such as the location of the name of a river, or relatively fixed, such as a boxed spot height. Alphanumerics contain classifications of cartographic information by type size, type face, and colour which are not retained when the word is spoken, so that the spoken town name, as distinct from the alphanumerics on the map, contains no information of population size. A spoken river name does not in itself convey that it refers to a river, unless prefixed by the word river, this being conveyed on the map by a combination of type size, type face, colour type, and positioning of individual letters within the name in association with the depicted meanderings of the river. Thus, even the alphanumeric information cannot generally be verbalised directly without some information loss.

The facility with which the information portrayed on the map can be verbalised and understood correctly is so important for many aviation purposes that any serious examination of the user's requirements would lead to the expectation that ready verbalisation would be a feature of batteries of tasks designed for the evaluation of aviation maps. Yet it is rare to find any verbal tasks at all. Aviation maps are not yet designed to facilitate verbalisation of the information on them.

Koeman[520] suggested that it was necessary to study modes of speech as a guide to the communication principles which should be followed in cartography. It is known that the success of matching a verbal description to a pattern depends on the complexity of the pattern more than does the success of matching two visual patterns (Cohen[238]). It would be expected that ability to recall the verbal form of cartographic messages might depend on the extent to which they had been converted into visual forms, and that this conversion process could be achieved more readily for general classes of cartographic symbol than for subclassifications of them (Bahrick and Boucher[521]). It is not known however whether these hypotheses, derived from non-cartographic sources, remain true for map symbology.

Given the need for verbal cartographic messages, the question arises of the form they should take to minimise errors, confusion and misinterpretation. In addition to technical improvements in voice transmission (AGARD Advisory Report 19, 1969 (Ref.522)), known sources of ambiguity in military messages can be minimised, and the ability to recognise potential ambiguities and confusions in received messages (Wilson[523]) might be used to reduce errors further by requests for further data about messages which seemed unclear. Wilson's[523] findings also suggest that intelligibility might be improved if a strict adherence to prescribed message formats is dispensed with if required. More specific recommenda-

tions, such as that by Loucks[524] in describing heading changes, could also be followed, and new voice communication philosophies, designed to achieve high intelligibility under unfavourable conditions (Camp[525]), could be considered in terms of their relevance to verbal cartographic communication.

The issue of cartography as a language is pertinent to the verbal transmission of cartographic information, in that, in so far as it is a language, it should be possible to formulate and use rules for translating cartographic concepts into verbal ones without major loss or distortion of information in translation. It does not follow that there must be a corresponding verbal term for every cartographic relationship and structure, but merely that a common logic can be applied. Although this theme has been much discussed and debated, there remains a gulf between the theoretical concept of cartography as a language and the practical application of its terminology to resolve real problems, even if it is conceded that cartography is a language, a claim which is itself disputed (Robinson and Petchenik[495]). Perhaps in the future, an approach based on linguistic analysis may provide a practical evaluation tool for maps, and for assessing the facility with which their contents can be verbalised, but such an approach currently seems impractical for aviation purposes.

In principle, it is possible to express cartographic information verbally to meet the requirements of some aviation tasks. McGrath et al.[322] demonstrated the feasibility of plotting target locations from verbal descriptions by the pilot, and showed that this could be as accurate as plotting by the pilot himself since plotters could track the progress of an aircraft from the pilot's descriptions. Taylor and Hopkin[151] demonstrated that verbal topographical descriptions of map positions could enable them to be located as accurately as when grid references were given for them, although accuracy was somewhat dependent on cartographic information density with verbal descriptions, and independent of it with grid references. These studies, having shown that verbal descriptions are feasible, indicate that the problem is to optimise their efficiency by drawing up rules to be followed when compiling them. It would be expected that performance both in formulating verbal descriptions and in understanding them would improve with practice. It would also be expected that verbal descriptions of certain kinds of cartographic relationships might be inherently ambiguous or confusing, and best avoided. Verbal descriptions of routes or pin-points clearly must involve a selection of the most appropriate relevant cartographic material. Attempts at verbal descriptions of the map of even a small area reveal the practical limitations of words and the cumbersome nature of verbal methods in providing sufficiently detailed descriptions, for example, to enable the map to be redrawn from them.

An assumption implicit in the study of the verbal tranmission of cartographic information is that there should be a close, and perhaps a one-to-one, relationship between each verbal concept and each cartographic one, and between each word or phrase and each map symbol, convention or relationship. However, just as computers offer an alternative to maps as a data storage system (Harvey[465]), so computer languages offer an alternative to maps in providing a set of concepts to be verbalised, and may provide a more comprehensive and precise description than either words or maps of some concepts concerned with patterns and spatial relationships. Thus the feasibility of employing verbal descriptions based on computer concepts rather than on mapping ones can be contemplated in the verbal transmission of cartographic information.

CHAPTER 8

PRINCIPLES OF INFORMATION PRESENTATION ON MAPS

8a DISCRIMINATION AND MEANING

Map design is the application of principles of information display to maps. Many of these principles are applicable to other displays than maps. Some of them have little application outside of cartography, such as the principles of shadow shading in relief representation. Knowledge about discrimination and meaning is fundamental to the design of all representational symbolic displays, including maps.

Sensory factors involved in the detection, discrimination and resolution of complex visual information have been reviewed in Section 3a. Perceptual and cognitive factors involved in the recognition, identification and interpretation of sensory information were discussed in Section 3b. Map design has to take account of what can be discriminated reliabiy and what meanings can be and are attributed to various codings, classes of symbology, individual symbols and information categories. Although findings about what is discriminable in other contexts may not remain valid for maps, differences which could not be discriminated in other contexts are unlikely to be discriminated on maps; therefore, negative findings on discrimination may have nearly universal validity. With regard to meaning, the application of general principles, though suggestive, may seldom be productive without verification in the context of the map. So much of the meaning, and particularly the plausibility of errors in assigning meaning, is dependent on the specific map context, and on the extent to which the meaning of the context has been understood. Meaning also depends on whether it is intended to be self-evident by using pictorial conventions, or relies on learning and remembering where there is no evident visual relationship between the symbol and what it represents.

To be most useful, guidelines for map design should be general, reliable, valid, firmly based on sound evidence, and not the subject of factual or theoretical dispute. Few guidelines withstand such rigorous criteria.

There is no single accepted approach to display design. Singleton[110] noted three practical approaches, based respectively on checklists, formal procedures and behaviour theory. Easterby[96] noted three theoretical approaches – language models, information theory, and Gestalt theory, and, in examining coding in relation to perceptual organisation, he distinguished between visibility and perceptibility, the latter being concerned primarily with clarity, stability and figure-ground relations. He also noted that meaning can be construed as structure or as signification. General theoretical frameworks of display design are not yet sufficiently established for a single set of procedures to be followed. Even if they were, their generality would have to be evaluated with care, to ascertain which conditions must be satisfied before they can be validly applied to design practical displays. Maps may not be sufficiently like other displays, or at least not sufficiently like the other displays which have been the subject of studies in display design, for recommendations on display design to remain valid for them (Hopkin[78]).

Most maps are used for a variety of purposes under different viewing conditions. Systematic design should ensure that the physical characteristics of the map image meet the minimum requirements for discriminability and legibility under all the conditions of use. The smallest contrast ratio and line weight, for instance, should be determined by the minimum necessary for map reading under the most difficult operational conditions. Unfortunately, most maps tend to be designed to provide a clear, legible and pleasing image under the near optimum conditions in which they are drawn. If multi-purpose topographical maps strictly adhered to minimum operational requirements, their appearance under ideal viewing conditions would lack the subtlety, and detail that many observers expect in a well-designed map. The cartographic community argue with some justification that they are unable to design maps for the most critical conditions because of the absence of definitions of operational requirements in cartographic terms. In the case of hand-held maps specification of these design minima is hindered because the observer can often overcome inadequacies by bringing the map closer to the eye or by highlighting important information in pre-flight planning. Human factors research is usually necessary to identify critical operational requirements and to translate them into cartographic terms, and few production agencies seem to have ready access to such expertise.

Human factors research concerning minimum requirements for map design under non-ideal viewing conditions is sparse. A significant proportion of this work has been with the legibility of alphanumerics under low levels of illumination (e.g. Crook et al.[36]). This has been discussed in Chapter 5c. In studies of search performance using eye movement recordings, Enoch[526] and Townsend et al.[450] deliberately degraded discrimination on maps by presenting blurred images. More recently, a number of reports have been issued concerning the legibility of maps viewed in various types of map display (Carel et al.[196]; Barrett et al.[345]; Taylor[100]; Hitchcock[527]; Barnard[406]; Wong and Yacoumelos[528]). The practical value of these experiments can be judged by the extent to which the results are presented in cartographic terms.

A glance through the illustrations in any text on cartographic design, such as that of Keates[120], shows that the coding of map information relies on point, linear, area, and alphanumeric symbols, varying their form, dimensions, colour and visual texture. A fundamental principle of display design is that variations in coding should be associated with variations in meaning. Unintentional variations are common on maps because of factors associated with their complexity such as overprinting of symbols, ink opacity, simultaneous contrast effects and because of variations in production control, such as ink strength and dot screen density. Generally, it is good cartographic practice to avoid designs with large unintentional coding variations as these may lead to confusion and misinterpreations. Thus, there is a requirement to know how much variation can take place before a difference can be perceived. Furthermore, when the intention is to enable discrimination to take place, it is important to know how reliably this can be achieved for a given difference in the physical stimulus.

If a series of discriminations is required, it is necessary to know whether this variation should be in steps of constant magnitude or should follow some exponential, logarithmic or other function to ensure reliable discrimination and visual equivalence of the steps. This requirement applies not only directly, for example to circles of increasing sizes, to lines of increasing thicknesses, or to a series of hypsometric tints within a single hue, but also to more complex visual textures and to technical processes during map production, such as cross line screens, tint screens, vignetting, hachures, and hill shading. In view of the psychophysical preoccupation with just noticeable differences, it would be expected that some practical guidance could be given on this topic for map designers, based on the application of Fechner's law that the increments in successive steps follow a logarithmic relationship, with each successive one a constant proportion of the absolute magnitude of the preceding stimulus. Unfortunately for cartography, the universality of this law, and indeed its validity, have been challenged (Stevens[176]) and guidance must therefore rely mainly on specific experimental findings rather than on general principles.

A study by Ekman et al.[102] found that the discriminable differences between certain cartographic symbols followed a power function, in agreement with Stevens' proposal. Power functions were also used to account for findings on discriminable lengths, areas and volumes (Ekman and Junge[180]). Earlier, Williams[529] had concluded that Fechner's law could not account for his findings on equal appearing intervals of a grey scale for use on maps. The curve of his grey scale could be used to derive equal appearing intervals for other colours, except for light ones such as yellow (Williams[178]). Williams[530] defended the validity of his findings against criticism, and independent confirmation came from the work of Jenks and Knos[94] who showed that in selecting a set of self-adhesive shading patterns for affixing to coloured maps the best set was obtained by applying Williams' findings. The US Department of Defence Standard Printing Screen Catalogue offers a non-linear range of percentage printing screen values at equal visual intervals, based on psychophysical data.

Flannery[182] found a non-linear relationship between perceived size and actual size of circles and wedges, but bar symbols could be graduated on a linear basis. Meihoefer[531] also examined circle symbols on maps, and encountered the psychophysical effect that their perceived size is not linearly proportional to their area. He suggested that it was necessary for cartographers to know and follow principles of visual perception when designing maps so that, for example, a circle which appeared to be doubled in size rather than one which actually was doubled in size, would be used if it was necessary to show this relationship. He also pleaded for a map legend, so that comparative rather than absolute discriminations would be possible. His findings were subsequently more widely published (Meihoefer[532,533]). Olson's[505] findings suggested that the discriminability of circles on maps can probably be improved by training.

Wright[181] examined the relationship between relative visual distinctiveness and line width on maps, with a view to selecting an optimum set of line widths. He criticised psychological findings on discriminable differences as of little help, because by cartographic standards they relied on crudely drawn forms and lines. However, Wright's findings could be accounted for by Fechner's law. Crawford[183], seeking to increase the visual effectiveness of monochromatic maps, examined the perception of graduated circles and line widths, and showed that the psychophysical properties of grey tones can be comparable to those of black ones. Severud[534] compared solid lines with various types of broken line, for mapping purposes. He was primarily concerned with the relative visual importance assigned to various kinds of line, rather than their relative discriminability, but he found that his subjects could not agree on the relative visual importance of the lines.

The apparent preoccupation of cartographers with the psychophysical scaling of map symbols arises from their extensive use to convey quantitative data on thematic and statistical maps. The validity of psychophysical data derived from experiments in non-cartographic contexts has been questioned by McCleary[503]. Whereas psychophysical scaling of symbols may seem acceptable when viewed on map legends, it is more important that it produces fewer confusions and improved identification performance compared with other methods of scaling when the symbols are viewed in a map context. Wagenaar[177] contended that the argument over the laws of visual discrimination may be sterile since under many of the most important conditions the competing theories are so similar in their predictions that it does not greatly matter which is followed. It is also important to remember however, in dealing with discrimination, that the map has to be designed not to cater for discrimination under average circumstances but preferably to retain discrimination under the least favourable operational conditions with an adverse physical environment, and eyesight standards at the minimum accepted level.

On topographical maps most differences in coding are intended to convey qualitative differences in meaning. Psychophysical data are only relevant to the extent that they inform the cartographer about the size of physical

differences in the symbol needed for reliable discrimination. Most topographical symbols use redundant coding, and discrimination is based on more than one coding dimension. The sizes of the physical differences depicted by one coding dimension may seem different from those depicted by another redundant dimension. Psychophysical research has so far failed to examine multidimensional symbol coding. Information on the discriminability of topographical map symbols, is mainly derived from studies of performance on search and identification tasks rather than psychophysical experiments (e.g. Taylor[100]; Potash[535]). Hypsometric tints represent quantitative data concerning terrain elevation and their design should be consistent with psychophysical principles. The coding of hypsometric layers will be discussed in detail in Section 8d.

Williams[200,201], and Williams et al.[256] adopted an empirical approach to measuring discriminability of symbols on complex displays. He recorded eye movements and fixations during search for specified targets and plotted discriminability gradients for individual coding categories based on the probability of fixations falling on similar non-target items in the display. A low probability of a non-target fixation indicated a high discriminability from the target. His results demonstrated the importance of colour coding in determining discriminability of symbols during visual search. Better discriminability and a more structured search pattern was achieved with colour coded displays compared with achromatic symbols.

Studies of form discrimination carried out in non-cartographic contexts indicate variables that may be relevant to map design. Form discrimination is affected by the time available for it, and by the nature of the judgment required. If it is necessary to say simply whether stimuli are the same or different, how long this takes depends on how many ways they may differ (Nickerson[536]). Whether forms are judged to be the same or different may depend on what has gone before, and on instructions about what to look for (Kantowitz[537]). Performance may also depend on whether the forms being compared are judged to be equivalent (Clement and Vernadoe[538]), and in making these judgments subjects may be unable to obey instructions on the strategy they should adopt (Clement and Weiman[539]). Judgments about relative magnitudes may be affected by the context in which they are made, but also by the kind of response required (Ross and Di Louo[540]).

Overprinting and clutter affect form discrimination. The ability to discriminate and identify symbols rapidly when varying densities of symbols are presented may be limited by what can be recalled rather than by what can be seen (Teichner et al.[541]). Legibility of a particular digit, as measured by times and errors, was degraded by overprinting multi-coloured symbols, though the exact nature of the impairment found was not clear, being explained in terms of hues but also explicable in terms of brightness (Smith[542]). A study by Williams and Falzon[543] indicated that for certain simple forms such as squares and circles, it was possible to introduce various overlays and still retain effective discrimination and recognition of their general form category.

Sternberg[544] believed that two separate stages could be analysed in discriminating and recognising a form, firstly an encoding of its basic visual properties, and secondly comparison, or a series of comparisons, with memorised information. The well-known findings (e.g. Bierderman and Checkosky[545]), that stimuli can be discriminated more rapidly if they differ independently and redundantly on more than one psychophysical dimension, may hold true for maps, but not be of much practical help to map designers. Such studies, and that of Stone[546] on the effects of redundant information, have been conducted mainly to test theories of serial or parallel information processing rather than with any practical application in view, to cartography or elsewhere. The above studies, not directly concerned with maps, provide a glimpse of the numerous factors which may influence the discrimination of information on maps, and suggest hypotheses which could usefully be tested with cartographic material.

8b SYMBOLOGY

Human factors handbooks provide guidelines on the choice of visually discriminable forms. They indicate the need for individual forms to contain sufficient distinctive attributes for a self-evident unambiguous label to be assigned to each. They suggest how many different examples of each form, differing in size, brightness or other common psychophysical dimensions, may be used without incurring significant errors in absolute judgments. In principle, therefore, much of the information needed to devise a set of unambiguous cartographic symbols is already available, either as specific recommended forms or as rules for devising and proving new sets.

Certain differences from standard conditions apply to maps, and these may need to be considered, but there are no serious obstacles to be overcome in doing so. On maps, judgments may be relative rather than absolute, in regard to sizes or hypsometric tints for example. The designer may have to modify his proposals according to the requirements for spatial precision, and for the juxtaposition and overlaying of other symbols. While it may be necessary to allow for the complexity and lack of uniformity of the visual backgrounds against which the symbols on maps have to be viewed, nevertheless there is a large body of evidence which can be used in selecting sets of cartographic symbols, and the experimental techniques required to verify their efficacy are not innovative, although they may call for access to specialised cartographic printing processes to prepare suitable experimental material. Even so, the costs of conducting a typical experiment on aviation maps, whether or not it requires specially prepared cartographic material, are small compared with those for experiments requiring a flying programme or flight simulators.

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HUMAN FACTORS IN THE DESIGN AND EVALUATION OF AVIATION MAPS,(U)
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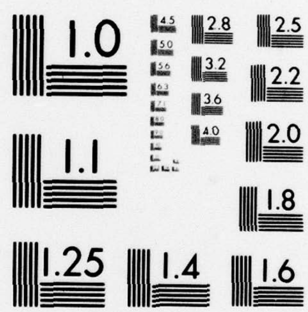

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

In view of the above, it is surprising that definitive evidence on the choice and discriminability of most map symbology does not exist, and much of the basic experimentation necessary is only being done now, or has still to be done. What has been done mainly concerns unidimensional symbols for coding quantitative data on thematic maps. This is not to say that all map symbology is inadequate; far from it. But it does mean that objective evidence on how good it is, and on how much it might be improved is not available. If a map proves unsatisfactory for a task it may be impossible to judge whether alternative methods for portraying the same information would be satisfactory, or if the task is fundamentally over-ambitious or inapproriate, so that the problem is not a matter of portrayal.

Standardisation

Standardisation of symbols to ensure that specific meanings are consistently associated with specific visual characteristics is fundamental to cartography and to all other effective means of graphic communication. The symbolism of cartography has developed and evolved over centuries of mapping, to the extent that numerous conventions have been accepted for common use, and hence become standardised. Some forms of cartography lend themselves to the adoption of standard symbology better than others; topographical maps have evolved conventions more readily than thematic maps where the most effective symbols tend to vary depending on the specific information to be communicated. Standardisation is a feature of individual sheets on thematic maps and of series of maps in topographical cartography. Here, consistent interpretations are ensured by strict adherence to a legend or design specification. In aviation, formal international standardisation agreements exist, governing different map series produced by various agencies, such as those drawn up by ICAO in Annex 4 to the Convention of International Civil Aviation (ICAO, 1967 (Ref.156)). Here the need for enforced standardisation is greater because conventions for depicting air information are not sufficiently well-established to prevent variations in usage. To ignore conventions and standards invites the possibility of confusions and misinterpretations which in flight can at the very least reduce operational efficiency and at worst endanger lives and reduce flight safety.

Several authors have discussed the need for standardisation of map symbols, including Ratajski[498]; Board[547]; Kikishov and Preobrazhensky[548]; Robinson[549] and Morrison[473] and Brandes[550]. Mostly, they are concerned with the need to adopt standardised symbology. Some have proposed a systematic rationale for deriving standardised symbol sets (e.g. Morrison[473]). It is broadly accepted that a cartographic syntax should be used to derive sets of symbols so that their appearance reflects the similarities and differences in meaning which they are intended to communicate. Most conventional topographical maps have evolved with such characteristics. The problem with standardisation is that many symbols become accepted and adopted with no objective evidence to confirm that they are the most effective symbols beyond the fact that they are in common use. Where they are not the most effective that could be used, the designer may be faced with the difficult choice between a bad convention and a good but novel innovation. Standardisation agreements, and most map specifications for that matter, are rarely based on objective research and empirical investigation of the effectiveness of alternative symbology.

Locational and Representational Information

Symbols on maps convey information regarding the location, nature and quality of features, objects or phenomena in geographical space. The locations of these phenomena can be defined in absolute terms in relation to the earth's surface; cartography attempts to convey this information by positioning the symbol as accurately as possible on the map within the limits of space and scale imposed by the medium. Representational or qualitative information concerning the nature of a given feature is conveyed by the graphic variables of shape, size and colour. The need to convey information about the nature of features often interferes with the ability to represent their locations accurately, and vice versa. An increase in scale invariably necessitates a reduction in the precision of locational information by the generalisation and separation of features in order to achieve a meaningful, legible representation. Conversely, the choice coding for symbolising a feature is constrained by the need for the symbol to be positioned accurately and unambiguously, and by the juxtaposition and separation of other symbols.

Classification

Two aspects of the design of map symbols can be distinguished. The first concerns the manipulation of graphic variables to enable one symbol to be differentiated from another. The second concerns the association of graphic differences with distinctions between the features represented, i.e. the referents.

Symbols could be classified on the basis of their geometric or graphic form but more useful classifications are based on the nature of the features that they represent. Map symbols may be classified as referring to points (non-dimensional, indicating a place or location), lines (one-dimensional, a boundary or route), or areas (two-dimensional, a forest or lake). Symbols for volume, representing three-dimensional geographical phenomena, occur frequently on thematic maps. Hill shading represents the slope of the landform in an area and could be described as an area symbol. Keates[120] points out that a given feature may be represented as a point, line or area depending on the scale of representation. On a large scale map a town may be depicted in outline or a road shown as varying in width and hence area, portraying the plan dimensions of the feature. On a small scale map, detailed planimetric representation of outline and width may be graphically impossible to draw to scale and if it were possible it might not be resolved by the eye. Hence, the classification of symbols are referring to points, lines and areas is not absolute but relative to the scale and kind of information represented.

Robinson and Sale[95] differentiate further between points, lines, areas and volumes of geographical phenomena according to the method of scaling or differentiation of the data, on nominal, ordinal or interval scales. Nominal or qualitative data are in mutually exclusive categories and convey no information on the order or ranking of phenomena. Most topographical features are distinguished in nominal categories. Ordinal scaling makes some statement about the order, rank or relative magnitude of features in addition to making qualitative distinctions, such as large towns or major roads. Interval scaling gives information regarding the distance between ranks such as differences in elevation in metric or imperial units of linear measurement. In theory, a system of symbolisation based on this two dimensional cross-classification of point, line, area and volume phenomena on the one hand, and nominal, ordinal and interval scaling on the other could provide a simple means of systematically structuring the grammar, and the semantic and syntactic dependencies of cartographic language. In practice, this system has not evolved because there are only three basic graphic marks – dots or points, lines, and area markings (patterns or colours) – that can be made on maps to represent the four classes of geographical phenomena. Each of these markings can be used to portray nominal, ordinal and interval data. Because these methods of scaling are not mutually exclusive, the same kind of marking can be used to convey both nominal and ordinal information, or ordinal and interval information, or nominal and interval information, or nominal, ordinal and interval information together.

In discussing information and symbols on maps, Keates[484] makes two fundamental statements about the nature of map symbolism. Firstly, he points out that for any feature, only a selection of the total amount of information that it is possible to know about that feature is represented on the map. Highly selective information is obtained in a geological survey. Depending on the scale and envisaged use of the map, only some of the differences between features measured in the survey will be portrayed by the cartographer. The map as a whole, and each symbol in particular, are both highly abstracted selections of information that the cartographer has judged to be worth communicating.

Keates' second point, related to the first, concerns the fact that the function of a symbol is mainly to classify and categorise geographical phenomena. Features are grouped together according to certain characteristics that they have in common and they may be represented by the same symbol even though they differ in other respects or exist at different locations. Classification may be on the basis of a major characteristic that the features share, such as the general classification "roads", or it may be a more detailed classification in terms of smaller groups within a general class, such as the sub-classification of roads according to width and surface. Qualitative and quantitative differences may form the basis of class distinctions. The formation of classes normally is a systematic process, beginning with the definition of major categories, and identifying sub-divisions of features within these broad groupings. In this way, the symbol system is organised in a hierarchical structure and the grammatical relationships between the symbols can be indicated to the user by similar and dissimilar codings. The general principle followed here is that a self-evident, ordered and logical structure linking the graphic variables and their referents will lead to more efficient communication than a structure of visually unrelated symbols, associated with features that are related in the environment.

Graphic Variables

Shape, size and colour are the basic graphic coding variables that are manipulated in the design of map symbols. Shape refers to form or outline of symbols, regular and irregular, representational or abstract, drawn in plan, profile or as an abstraction of the function of the referent. It also concerns the qualities of visible pattern and texture used to represent area features by repeated or combined dots or lines, and variations in continuity and structure of symbols depicting linear features. Variations in the orientation of shapes may be used to make distinctions without changing the form or outline.

Variations in the sizes of points and lines are commonly used to make qualitative and quantitative distinctions in the meaning of symbols. These range from the minimum size at which the eye can detect a brightness change, to sizes well above the threshold for visual detection determined by the number of intermediate size differences that need to be discriminated and identified, and by the size variation required to give the desired visual emphasis to the feature in a cartographic context. Lines are the most common graphic element of most topographical maps. Hence they are often termed line maps to distinguish them from, say, annotated aerial photographs. Size variations in line widths or "weights" together with differences in line length form the detailed basis of a large proportion of most map images. The size of symbols representing areas is determined by the location of the boundaries of the area. Size dimensions may be manipulated when the map scale does not permit the representation of areas in planimetric form. Size may also be varied in pattern and texture coding of area features to indicate quantitative difference such as in the density of objects within an area or differences in importance and prominence.

Colours on maps vary in hue, chroma and value. Variations are achieved by the use of different printing inks, by differences in ink strengths, by screening or tonal differences, and by overprinting and juxtaposing other coloured areas. Colour coding has unique attention-getting properties but its value for coding small differences between features is reduced by difficulties in the absolute identification of large numbers of different colours. Colour coding will be discussed in detail in Section 8d.

Shape, size and colour are often used together as redundant coding to indicate the nature of referents. Shape and colour are frequently combined in the design of topographical symbols. Limitations on the absolute identification of colours often restrict the use of colour to conjunctive coding, to coding general classifications of features or to coding for tasks with a large search component. Shape coding on the other hand, lends itself to numerous variations that can

be easily recognised and identified. Thus, shape coding tends to be used for representing smaller differences or sub-classifications of features (disjunctive coding).

Studies of the comparative influence of various dimensions of symbols on recognition and identification performance have been very numerous. The answers obtained usually depend as much on the choice of symbols, of tasks, of experimental conditions, and of measures, as on the dimensions themselves. Kunnapas et al.[551] analysed some simple symbols in terms of their similarity on several dimensions rather than on a single one. Erickson[552] reported that shape and hue were marginally more influential than size or brightness. Colour was better than shape on tasks involving search according to Williams[200] and Smith and Thomas[240]. In one of the few experiments of this kind carried out on maps Chirstner and Ray[103] found that numerical coding was superior for identifying tasks and that colour coding was superior for locating and counting tasks. The results of many of these experiments are summarised in handbook recommendations on the choice of forms and symbols, many of which depend on somewhat tenuous evidence that is nevertheless better than no evidence at all.

More specific studies of map symbols have tended to follow one of two methods. Some start by collecting samples of map symbols in use and then categorise and study them (e.g. Koponen et al.[29]; Adams[490]). Others start by studying symbols out of the map context (Williams[554]), sometimes to achieve a particular effect, such as impressions of volume (Ekman et al.[180]), of circular area (Meinhofer[533]), of square area (Crawford[183]), of line types (Severud[534]) or of graduated point symbols (Flannery[182]). An alternative is to try to simulate maps (Hanby and Shaw[224]) which has the advantage of permitting more adequate control over experimental variables and the disadvantage of trying to prove that the findings may be generalised to real maps. There is some evidence that certain physiological measures, as well as behavioural ones, may be sensitive to differences between symbols in the ease with which they are recognised (Chainova et al.[555]).

Clarity and Legibility

Clarity and legibility are fundamental requirements for the design of map symbols. Clarity and legibility can be achieved through the choice of lines shapes and colours, to comply with the limits of visual acuity and discrimination discussed in Section 3a. High contrasts between symbols and backgrounds are essential for small detail to be resolved, particularly under non-optimum viewing conditions. Minimum sizes should be determined by the smallest component of the symbol that has to be recognised.

In addition to the above, some general statements can be made about the characteristics of successful cartographic symbols using concepts drawn largely from Gestalt psychology. In graphic design, simplicity is a virtue; concise and precise signals are more efficient than elaborate and complex messages, particularly when the user has limited time and when his task loading is high. Simply stated, the shape of map symbols should be distinctive in general outline, not in fine detail. Symmetry, continuity, closedness, unity, and figural goodness are desirable characteristics when they can be incorporated without affecting the meaningfulness, appropriateness and pictorial quality of the symbol. (Wood[188]; [227]; Dent[556]; Keates[120]).

Koponen et al.[29] examined the meaningfulness or association value of a sample of map symbols by measuring the ability of the symbol to evoke an immediate and correct response of the object it represented. Pictorial symbols were judged by subjects to be the best method of symbolisation, related objects were judged the poorest, and geometric, part of the whole and verbal symbols were considered to be only moderately acceptable. Easterby[557] has pointed out that to achieve pictorial quality, in which the symbol looks like the object to which it relates, it is often necessary to introduce complexity, thus producing a conflict with the need for simplicity. Good design often depends on the correct balance between pictorial quality and simplicity.

In an earlier paper discussing machine displays, Easterby[231] summarised some of the basic principles of symbol design, which also apply to maps.

(1) Figure/ground. Clear and stable figure (symbol) to ground articulation is essential.

(2) Figure boundary. Figures should be bounded by a contrast boundary in preference to a line boundary. Where the symbol involves more than one graphic element, the most important should have a solid contrast-bounded element.

(3) Geometric forms. Simple geometric shapes should have a solid rather than an outline figure.

(4) Closed figures. Line-bounded figures should form a closed figure unless discontinuity is essential to the meaning. Where discontinuity is important, it should be clear and unequivocal to avoid misinterpretation due to the psychological phenomenon of closure.

(5) Continuity of figures. The smoothest, continuous outline for the figure should be used, and where discontinuity or irregularity is required it must be unambiguous, to avoid perceptual smoothing.

(6) Simplicity. Symbols should be as simple as possible because fine detail does not facilitate unambiguous and rapid interpretation.

(7) Symmetry. Symbols should be as symmetrical as possible, unless asymmetry contributes to the meaning of the symbol.

(8) Unity. Symbols should be as unified as possible by integrating diverse elements within an outline (e.g. boxing spot heights) and by consistent use of the same size and proportions of individual elements when they repeat (e.g. cross-tie bars on railway line symbols).

(9) Orientation. The prevailing outlines of the symbol should attempt to follow the main horizontal and vertical spatial axes.

Most of these statements are based on design experience rather than empirical research. There is some evidence to indicate that increasing the visual complexity of a symbol reduces the probability that it will be recognised (Williams and Falzon[543]). The findings of Van Roy and Morrison[558] supported the view that simple pictorial map symbols are more readily recognised than sophisticated complex ones. Taylor[100] presented empirical evidence for the desirable characteristics of map symbols in a comparative evaluation of conventional and special-purpose maps for moving map displays. Similar evidence can be obtained from studies of the legibility of maps in television displays (Harrison[559]; Marsetta and Shurtleff[560]; Wong and Yacoumelos[528]; North and Williges[561]; Streeter et al.[456]).

Hopkin[70] suggested that existing human factors principles should be applied to map symbology, to allow their relevance to be empirically tested. One problem in deriving principles of map symbology from empirical data is that assessments of the utility of a map symbol may depend on the task. Different results may be obtained if, instead of traditional search or counting tasks, a measure of decision quality is adopted, such as that which Silver et al. proposed (Ref.562) and tried (Ref.512).

Harrison[148], in his controversial paper, raised some pertinent issues about map symbology. He believed that to have a large number of symbols was self-defeating, and that in many instances discrimination should rely on topographical features rather than symbology, for example in relation to reservoirs and dams. He wondered if the most important features should cast shadows to emphasise them, but queried the logic of including symbols in perspective on maps in plan view. Further discussion of map symbology are contained in papers by Howey[336], Wulfeck et al.[101], and Lichte et al.[56].

8c TYPOGRAPHY

It is somewhat surprising to read now the conclusion by Lichte et al.[56], in their review of map reading studies in relation to radar scope interpretation, that much of the dependable knowledge about map design concerned the readability of symbols and the legibility of typefaces. Keates[563] noted that the particular requirements of map typography, in contrast with book typography, included the legibility of every individual letter and the employment of typefaces as information codes, and he examined critically the legibility of traditional typefaces on maps. Poulton[564] distinguished two measures of legibility, namely rate of comprehension and rate of skimming, but although the latter measure was seen as appropriate when the reader is interested only in certain parts or aspects of the material, it nevertheless does not seem to be directly applicable to many map reading tasks. Some of the typographic requirements of maps were reviewed by Gardiner[565], mainly by a systematic application of Burt's[97] recommendations on typography to cartography. Bartz[566] concluded from her analysis of the literature on typographic legibility that none of its major recommendations had been derived from, or verified for, maps, and that the measures used, mainly those referred to by Poulton[564], seemed irrelevant for map reading and led to conclusions which were probably invalid for maps. Much of the confidence of Lichte[56] and his colleagues about our knowledge of typeface legibility in relation to maps therefore seems in retrospect to have been unwarranted.

Cartographic textbooks, such as those of Robinson and Sale[95], Monkhouse and Wilkinson[139], and Keates[120], discuss typography in some detail, usually under the heading of lettering. Type can vary in the following ways (see Keates[120]) for illustrations of the terms used:

Fount (font) – general design, style or typeface (e.g. Times; Universal; Gill Sans: etc).

Roman (upright) or italic (slanted).

Serif, sans serif, or slab serif.

Case (upper or lower).

Size – height of letters, or more commonly of metal type body (defining point size).

Set – width (generally classified as condensed, normal or extended).

Body – size of ascenders and descenders in relation to distance between baseline and mean line (a large body having relatively small ascenders and descenders).

Weight – stroke width or thickness (generally classified as light, medium or bold), with its consequent modifications of set and design.

Colour

Density – opaqueness (affecting contrast and tolerance of various photographic and other processes).

(Strictly speaking, these last two variables are properties of the ink or the processing, rather than of the type itself).

100

There are many interacting effects among the above variables, depending in particular on the choice of font. In maps, a further variable may be the spacing between letters within a word, which can be expanded to fit other data or for functional reasons, for example if a name refers to a large region and is given prominence by increased weight rather than size. Also, the letters in a map name may not all lie in a single straight line, particularly if they refer to a curving geographical feature such as a river.

In cartography, the most fundamental distinction is between typefaces with or without serifs. Whereas Harrison[148] suggested that sans serif type should never be used on aviation maps, Monkhouse and Wilkinson[139] believed that serifs should not appear extensively on maps. Keates[120] was more cautious: in so far as serifs foster continuity they may enhance legibility, but large stroke variations, associated with serif rather than sans serif typefaces, may impair legibility and discourage the use of so-called modern typefaces with serifs at right angles and with symmetrical vertical stresses, which lack the inherent flexibility and subtlety needed to preserve maximum legibility. Keates noted the advantage for maps of founts with a full complement of weights and forms, since the fount itself, its Roman and Italic forms and its upper and lower cases may be of service in coding different cartographic information categories, leaving other variables, such as size and weight, to show distinctions within categories. It is also an advantage for maps to have type with a large body.

Two aspects of typography for maps are to some extent in apparent contradiction. One is the conclusion that, on the whole, psychological research findings on alphanumeric legibility, and the consequent recommendations on legible alphanumerics in human factors handbooks, have little relevance for maps. The other is that most common typefaces have been designed with great care and are basically highly legible. Psychological criteria of legibility emphasise possible errors caused by the confusion of individual letters with each other: in experiments, letters are often degraded deliberately by a variety of means, including short tachistoscopic exposures, blurring, and low light levels, to emphasise errors or prolong reading times until they attain statistical significance. Typographical criteria of legibility emphasise the balance and aesthetic qualities of individual letters, and the need for a coherent style for all letters in the fount. Neither approach is concerned with the effects of the multiplicity of cartographic backgrounds on the legibility of lettering. The conditions of use for which most typefaces or alphanumeric character sets were designed rarely occur on maps, the nearest approximation probably being boxed spot heights or names, which are never common. Thus, probable conclusions to be drawn are that there are no reasons for supposing that the general literature on typographic legibility would be valid for map design, but that equally there are no reasons for expecting gross improvements in legibility to accrue from specially designed lettering for maps.

Specially designed lettering would be intended to remain legible against a variety of backgrounds, but this variety implies that the only effective methods must rely on increased size, weight, body and similar physical attributes, combined in certain circumstances with more opaque inks and with high contrast colours chosen to remain legible when superimposed on, or near to, any other colours on the map. Such techniques could increase legibility, but at the cost of impairing the visual balance of the map and giving the lettering a visual obtrusiveness and emphasis which its operational importance rarely justifies. Many aviation map contexts, far from requiring a greater emphasis on place names, can dispense with them without operational penalty (McGrath et al.[132]). The cause of illegible lettering on maps is seldom the typeface itself, but more often an incorrect choice of size or weight, or excessive clutter or density of information. If the problem has arisen because photographic processing has degraded legibility, a change of fount alone will do little to resolve it. The intention here is not to discourage attempts to design lettering to meet the particular needs of cartography: such an enterprise would be challenging, and helpful if successful; but the resulting improvements, though tangible, are likely to be small, and changes in lettering are no panacea for other problems. Any specially designed typeface would be the result of a great deal of work if it included all the necessary forms and never seemed amateurish or clumsy, since it is easy to under-estimate the complexity, subtlety, aesthetic cohesion and legibility of the most commonly used and successful founts on existing maps.

Bartz[194] proposed that the speed with which a map can be searched provides a logical criterion for measuring the comparative legibility of alternative type on maps, and proceeded to use this measure in several search tasks (Bartz[509]). If different maps had different typefaces, but there was only one typeface within each map, typeface had no significant influence on search time. Where there were several typefaces within a map, search time depended mainly on whether the searcher knew beforehand the typeface of the lettering he was looking for. On the whole, typeface was not a main determinant of search performance.

Taylor[100] included variations in typeface in an evaluation of the legibility of topographical maps for aircraft map displays. The primary purpose in introducing typeface changes was not so much to enhance legibility as to ensure that lettering on a paper map was in a form which remained legible after microfilm processing and projection in moving map displays. The main methods, which were generally successful, were to increase size and to enhance contrast by greater weight and density, rather than to try different typefaces. The subject's task was to identify the characters in specified place names, river names, radio facilities labels, etc. Times and errors were recorded. Search remained a task component, but the requirement to search was reduced by indicating the location of targets on an adjacent map of the same area with the relevant targets masked from view. The fixed viewing distance of 480 mm was comparable to that for instrument panel mounted map displays in the cockpit. The results indicated that optimum type dimensions depended on the readability and inter-character redundancy of groups of letters. Whereas plantation names could be read with comparatively small dimensions, spot elevations had to be larger because each numeral had to be identified separately. In general, 8 point capitals (height 1.8 mm; stroke width 0.3 mm) were required for good legibility in familiar letter sequences,

such as radio aid notations, and 8 point lower case lettering was acceptable in labels and placenames. 8 point type was adequate for spot elevations in clear boxes, but 10–12 point type was required if contrast was poor, as in grid lettering. Bold colours, medium stroke widths, medium to wide letter spacing, 1:1 height-width ratios, and upright sans serif (Gothic) typefaces were recommended.

The results are in broad agreement with the standard human engineering recommendation of a height/stroke width ratio of 5:1 or 6:1 for low contrast, long viewing distance conditions, but the minimum height of 2.8 mm suggested for poor contrast conditions on maps is much less than the normal recommended height of about 7.0 mm for other visual displays under comparable viewing conditions (McCormick[106]). Such large type sizes are impractical on most topographical maps because of limited space and high information density. In most map reading tasks, the viewing distance can be varied, so that the map reader simply reduces his viewing distance if he has difficulty in reading the map. The facility to do this often seems to be assumed in the design of conventional topographical maps. This design principle no longer applies to maps in map displays when the viewing distance is fixed by a seat harness.

The legibility of type on maps is subject to degradation from numerous environmental conditions associated with flight. How far the map design must try and compensate for this degradation by changes in the typography depends on the operational significance of the typographical data on the map, the frequency and severity of the expected degradation, the feasibility of map usage under adverse conditions, visual balance, information density, and the extent to which departures from the optimum map design under normal conditions can be tolerated to satisfy exceptional conditions. To compensate for vibration, dim illumination, viewing through goggles, and other impairments to map legibility, type can be enlarged, increased in weight, altered in colour or density, or perhaps changed in case, serifs, uprightness, fount or set. Contrast may also be improved by lightening the background, and considering reflectance values. Under very adverse environmental conditions, such as severe turbulence or near darkness, it may become impossible to retain the legibility of typographical information on a map by modification to its design. The particular problems of red cockpit lighting and typography (Crook et al.[36]) have been described in Chapter 5c. Another problem, associated with maps for a moving map display, is the ability to read lettering which has been rotated. A preliminary experiment by Sgro et al.[567] suggested that this remains feasible, though the time required increases, particularly if the lettering is nearly inverted. However, finding the word and seeing it as a visual entity before reading it introduce problems in addition to that of legibility.

In comparisons between existing maps, the type used for a given information category is likely to differ between maps on numerous dimensions, so that even when a significant difference between the maps is found in the performance of a task it may not be possible to establish which design differences were responsible for the effect (Phillips and Noyes[568]). However, when special material is made to show separately the effects of independent variables, the resultant simplified map-like material differs so much from topographical maps in the cartographic categories, codings and information density and variety depicted that the generalisation of findings to real maps becomes speculative. This latter approach was followed by Phillips et al.[569] who concluded that type size and case were more important than fount or weight in influencing a search task. Type styles were not mixed within any single map, and type variations as a means of categorising map information were not studied. They were not concerned with adverse viewing conditions. Within these limitations, their findings were not incompatible with those of Taylor[100]). Phillips et al.[569] stressed the need to judge the legibility of type on a map not in isolation but with reference to the importance of typographical information in relation to other categories of portrayed feature.

The advent of computer-generated lettering for maps poses a new set of typographical problems since the intricate variations within the design of typefaces are not a feature of computer-generated lettering which, by comparison, is inflexible, crude and unwieldy. The problem arises of the questionable applicability of the findings on computer-generated alphanumerics to the legibility of computer-generated lettering on maps (Streeter et al.[456]).

Probably of greater significance for lettering on maps than most attributes of the typeface is where the lettering is put on the map, that is the positioning and arrangement of names. Some of the principles for placing names were illustrated by Keates[120]. Imhof[158] contended that there is one optimum position for each name within a map, and illustrated how, and how not to, position names. While it is generally true that there is an optimum position for each name, it does not follow that there must be an ideal position, or that every name selected can be included without clutter or ambiguity. Alternative criteria for positioning names, and the possible role of computers in positioning them, are topics requiring further study.

In choosing type and in positioning names, it is desirable to consider the peripheral visual cues which alphanumeric information on a map may provide, which assist a variety of tasks. If the letters which constitute a word are placed too far apart, the shape and length of the word, both useful peripheral cues in accepting or rejecting a word during search, may be lost. Ascenders and descenders, if very small, may fail to contribute to the initial rejection or recognition of a word peripherally. Weight, slant and colour may also be helpful peripheral codings. A fount which gives visual prominence to initial capitals might be advantageous too for certain tasks. Such hypotheses require verification, but indicate that the role of characteristics of type as peripheral cues might repay study.

8d COLOUR

Colour is used extensively as a coding dimension on maps. The principles governing the selection of colours are complex, drawn partly from aesthetic and utilitarian considerations, partly from convention and established practice, and partly from the mechanical and technical factors involved in the formation of the map image, which are constantly changing. Robinson and Sale[95] identify three reasons why colour is important in cartography. Firstly, they argue that it simplifies and clarifies the map image by reducing visual clutter, by facilitating figure-ground segregation, and by unifying and segregating aerial features. Secondly, the subjective, connotative effects of colour make it an important aesthetic element, with the result that unpleasant colour combinations may reduce the map's effectiveness. Thirdly, they point out that the choice of colour affects the observer's ability to discriminate fine detail, to distinguish shapes and boundaries and to read lettering.

It seems to be universally accepted that the use of even the smallest amount of colour on a map achieves an immediate improvement in the attractiveness of its appearance. Achromatic maps are dull and uninteresting in comparison. This pleasing effect of colour is common to all forms of visual display; on maps the problem is to distinguish between those principles of colouring which depend on the connotative effects and those that have functional and utilitarian value. Each may bring about improvements in communication, either by increasing the motivation and arousing the curiosity of the observer or by facilitating the interpretability of the map content. In military aviation, the attractiveness of maps is probably less important than in fields where commercial production agencies compete for markets, or say in education. Nevertheless, it would be foolhardy to ignore aesthetics totally, for instance when introducing a new map series, because a pleasing appearance may lead to quicker acceptance of the new product and overcome the traditional reluctance to change. On the other hand, where the important criteria are functional rather than aesthetic, it becomes relevant to consider whether colour coding significantly improves or degrades map reading performance and whether equally good or even better performance could be achieved at less production cost with monochrome maps. Balanced assessments of colour coding compared with monochrome coding of visual displays has been provided by Jones[570], Christ and Teichner[571] and Christ[572]. Most of the visual principles of colour coding on maps are discussed by Robinson and Sale[95] and Keates[120]. Discussion papers on the psychological, aesthetic and utilitarian aspects of colour in cartography are offered by Keates[502], Makowski[573], Robinson[98] and Yanosky[574]. The associational properties of map colours have been investigated by Van Der Weiden and Ormeling[501].

Illumination and Colour

As discussed in Chapter 5c, the selection of colours on most aviation maps is restricted by the requirements of red cockpit lighting. Aeronautical charts are invariably printed in black, blue and green colours and no other, to prevent the loss of contrast under red illumination. All three major topographical map series (ONC, TPC, and JOG) used in military aircraft operations avoid the use of red and orange colours. Electric blue was probably initially chosen for air information because it retains a high contrast under red illumination. There is evidence that few aircrew actually use red lighting to illuminate maps in present-day aircraft operations (AGARD[575]; Taylor[348]). Although the abandonment of this restriction on map colours would benefit the majority of aircrew, map production agencies are reluctant to alter their colour specifications while some aircrew continue to use red lighting.

Research on Colour Coding

Most of the principles governing the use of colour on maps reported in cartographic textbooks are based on practical experience rather than on empirical research. The human factors literature is rife with experiments comparing the relative merits of colour, shape and other codes on identification and search task performance. Only a few of these studies have been carried out on maps.

Christner and Ray[103] examined the relative effectiveness of various target-background coding combinations on maps. Three target codes were used: non-redundant colour, number and enclosed shape. The eight target colours were those recommended by Conover and Kraft[576] for eight- and four-step codes. They were approximately the same Chroma and Value, but differed mainly in Hue. Five types of map background were used: all white, solid grey, five shades of grey, five pastel hues giving good brightness-contrast with the targets, and five different patterns. Three variables affecting display complexity were examined: the number of targets (60 and 120), the number of coding levels (4 and 8), and the clustering of targets (high and low). Five subjects were used in a fully factorial design each performing five different tasks: locating, identifying and counting targets, and comparing and verifying target data in different areas.

The major findings regarding colour coding were as follows. Coding and complexity conditions did not interact. For the Identification task, number coding was superior to colour coding, whereas for both the locating and counting tasks colour coding was superior to number coding. Performance with coloured backgrounds did not differ significantly from that with non-coloured backgrounds. Furthermore there were no significant differences between performance with the four black and white backgrounds. They concluded that the optimum choice of target codes depended on the task to be performed. Colour coding was superior for tasks involving visual search, but numeral coding was an advantage when the task involved identification. It is reasonable to draw the further conclusion that when the task involves both search and identification a redundant or partially redundant combination of colour with number or shape coding is probably the most desirable. This is the standard practice on most topographical maps.

Christ and Teichner[571] summarised visual display experiments on colour as a completely redundant attribute. They concluded that the addition of completely redundant colour to size, brightness or already redundant combinations of size and brightness produced large improvements in identification accuracy (Eriksen and Hake[577]; Kanarick and Petersen[578]). The addition of redundant colour to alphanumerics, shape, size or brightness also had a large positive effect in reducing the time needed to locate and count alphanumeric targets (Brooks[579]; Smith[580]; Smith et al.[241]; Eriksen[552]; Eriksen[581]). These advantages for redundant colour depended on the subject being informed of the redundancy. Adding redundant colour without informing the subject impaired performance (Eriksen[581]). Redundant colour had an increasing advantage as stimulus density increased, according to Smith[580] and Smith et al.[241]. Brooks[579] found that as the number of redundant colours increased there was a slight decrease in the advantage of redundancy.

Studies of colour as a partially redundant code involving measurement of identification performance are generally comparisons of coloured and achromatic displays of the same material. Christ and Teichner[571] reviewed five such studies: Wong and Yacoumelos[528] on maps; Markoff[582] on embedded targets in a natural scene; Jeffrey and Beck on static aerial photographs; Kraft and Anderson[584] on dynamic aerial movie film; Fowler and Jones[585] on a real-time sensor display. In all cases, the subjects knew the redundant colour of the target. Only Markoff[582] showed an advantage for colour on identification accuracy; all the others found no effect.

With regard to search performance, partially redundant colour was an advantage when the subject knew the target colour. This advantage increased as the number of different colours in the display increased, but decreased as the proportion of non-targets with the same colour as the target increased. Not knowing the target colour made the addition of partially redundant colour a disadvantage (Green and Anderson[586]; Smith[587]; Smith[580]; Shontz et al.[588]).

The papers by Shontz[589] and Shontz et al.[588] are particularly important because they report an experiment in which up to 28 colours were used to indicate the location of features on maps. The authors pointed out that limits on the number of identifiable colours recommended in the literature on visual displays are not necessarily relevant to maps where search is an important task component. In their experiment they used sets of 7, 14 and 28 colours highly discriminable in peripheral vision according to discrimination gradients established from eye fixation data reported by Williams[590]. Circular samples of these colours were attached to maps adjacent to selected target features acting as a partially redundant code. The maps were from the sectional Aeronautical Chart series, some printed in their original colours and others photographed in black and white to give achromatic controls. The map areas were chosen to give four levels of map clutter and the number of objects in each coded category was balanced across conditions. Thirty-three subjects were presented with a sketch card containing a drawing of the target feature and a disc showing the appropriate colour code. Time taken to locate the target feature was recorded.

The results showed a significant advantage for colour-coded targets that was maintained for all code sizes. Colour-coding of targets was an advantage when the number of objects in each code category was eleven or less. Above this number, the advantage of colour coding was no longer maintained. There were no significant differences in performance between chromatic and achromatic map backgrounds. In conclusion, it was stated that colour coding for information location on maps was effective for at least 28 categories when the colours used were highly discriminable in peripheral vision and when the number of objects in each category was no greater than eleven.

Large numbers of colours have been shown to be usable by other authors. Hanes and Rhoades[591] showed that with extensive training an observer could identify 50 surface colours with almost complete accuracy. Bishop and Crook[592] estimated that by varying Hue, Value and Chroma as many as 60 colours may be distinguishable. The difference between these figures and the comparatively small numbers of colours used on most maps (6 to 12) is probably due to the limiting effects of memory for colours as well as economics. Shontz's[589] task was somewhat unrealistic in that subjects were always shown the colour of the target and they never had to learn it. Osterhoff et al.[320] demonstrated that achromatic charts were inferior to a standard chromic chart for maintaining geographic orientation under simulated flight conditions. They concluded that existing chromatic charts could not be adapted successfully to navigation display systems with no colour capability and that such systems would need specially designed achromatic charts.

In an experiment on decision making with maps displaying tactical information, Silver et al.[512] found colour to be most effective in aiding decisions when the density of facts was high. Their use of decision quality as an alternative to the more traditional measures of the effects of colour, such as search time and accuracy, reflected the need to ensure that findings are not an artefact of the chosen measure, and to use a variety of tasks reflecting the multiplicity of functions of many colour-coded displays. Findings about codings often depend on the chosen task, as in the study by Burdick et al.[593] and in Schutz's[594] experiment which demonstrated the reading time for various kinds of line symbols could be influenced by colour coding. Stringer[595], testing colour and readability in maps, employed measures derived from a repertory grid technique, and Stone[546] suggested that to some extent colour and form attributes could be processed in parallel in making comparisons between stimuli.

Taylor[596] reported a series of experiments on colour coding on maps including measurements of the visual conspicuity and visual separation of printing inks, and the scaling of hypsometric layer tints. He argued that the optimum selection of map colours was partly based on the visual distance between them as well as on the requirements for contrast and redundancy with size and shape codes. Sets of colours with maximum visual separability were very similar to colours used on popular, full-coloured aviation maps.

Tint Screens

In normal 'flat' colour or colour separation reproduction, the three psychological dimensions of colour (Hue, Value, Chroma) are varied in several ways: by using inks with different spectral compositions and different dominant wavelengths; by using different ink strengths; by adding grey; by superimposing one semi-transparent ink on another; by using half-tone and vignetted tint screens.

Half-tone tint screens are the principal means for varying the Value and Chroma of a given Hue. The effects of half-tone tint screens are twofold compared with a solid of the same colour: a half-tone screening increases the reflectance from the exposed white paper, and thus desaturates or reduces the chroma of the colour by increasing the reflectance of all other wavelengths apart from the dominant wavelength; secondly, the lightness or value of the colour is increased because the exposed white paper reflects more light than any subtractive hue. Half-tone tinting or screening therefore has the effect of decreasing chroma and increasing value compared with the solid of the same ink. Conversely, increasing the percentage of screening and the amount of ink falling on the paper, increases chroma and reduces value. The effects of screening on value depend on the reflectance of the ink: a smaller range of variation in value can be achieved by screening lighter inks such as yellow and some greens than with darker inks such as blues and blacks. With dark inks, exposing only a small percentage of the white paper by screening produces a comparatively large increase in reflectance.

In a half-tone tint screen, the lines of dots are printed at a particular angle. An angle of 45 degrees to the horizontal is normally used for monochromatic maps. On multi-coloured maps, each coloured screen must be orientated at different angles with a separation of 30 degrees to avoid undesirable moire patterns.

Half-tone screening is particularly important on topographical maps where large area features are often superimposed with point, line and alphanumeric symbols. In order to obtain adequate contrasts for overprinting the designer must use light colours for background features or use half-tone screens where the solid of the background colour is too dark.

A considerable amount of cartographic research has been devoted to the psychophysical scaling of tint screens, with the intention of producing sets of screens with equal appearing visual intervals. Williams[529] concluded that Fechner's law could not account for his findings on equal appearing intervals of a grey scale for use on maps. In a later paper (Williams[178]), he showed that the curve of his empirically derived grey scale could be used to derive equal appearing intervals for other colours, except for light ones such as yellow. According to Williams' data smaller differences in screening are required to make an equal visual difference in the light tones than in the darker tones, and the largest differences are required in the middle of the range. Williams[530] defended the validity of his findings against criticism by Robinson[597], and independent confirmation of his results came from the work of Jenks and Knos[94] who showed that in selecting a set of self-adhesive shading patterns for affixing to coloured maps the best set was obtained by applying Williams' findings, rather than by applying psychophysical log or power functions. More recently, Crawford[179] found no measurable differences between the perception of graduated symbols printed in black and grey tone. Ten percentage printing screens between white and solid (4, 7, 12, 21, 31, 42, 54, 67, 79, 91%) with equal appearing visual intervals checked by empirical research are used for the production of aeronautical charts (Anon[598]).

Variations in half-tone tint screens of the same ink are often used on maps to represent a set of variations in quantity, with each screen corresponding to a numerical value or interval. On topographical maps, tint screens are used in this way to represent intervals in height elevations above sea level. The design principle usually followed is that greater intensity represents higher numerical value (Keates[120]), or "the darker the Value (colour) the greater the magnitude" (Robinson and Sale[95]). Large quantities are normally shown by saturated hues which are low in Value; small quantities are shown by tints of low Chroma and high Value. In representing relief on topographical maps the reversal of this general principle would lead to increased legibility problems with superimposed information which tends to be densest in low lying regions.

Tone and Texture

Pattern and texture cues may be introduced by variations in half-tone tint screens, dependent on the size, spacing and orientation of the screen elements and the observer's viewing distance. For most applications, the size of the dots or lines and their spacings are usually so small as not to be resolved by eye at normal reading distances. Hypsometric tinting by dot screens is one example where textural differences are normally below the threshold for discrimination. On the other hand, discriminable single and crossed line screens with their solids have been used with success on some UK Ordnance Survey maps to represent relative relief whilst permitting absolute identification on the basis of texture cues. Textural cues are more commonly combined with tint screen differences for area symbols on monochromatic maps and for indicating qualitative differences on maps of geology, soil and land use. Jenks and Knos[94] found that for graded series of symbols observers preferred dot screens to irregular and line screen patterns and that fine textures were better than coarse textures. Robinson and Sale[95] reported that with dot screens having textures finer than 75 lines per inch pattern differences will not be discriminated, whereas textures coarser than 40 lines per inch will tend to be perceived as patterns rather than as tones. They also warned against the irritating visual effect of large areas of parallel lines when the spacing between the lines is greater than the width of the lines.

Value Differences

On the number of discriminable differences in achromatic half-tone tint screens, Robinson and Sale[95] concluded that a difference of 10% to 12% in percentage screening will usually be noticeable and that about six to eight shades of grey between a black and white is about the maximum that the untrained observer can discriminate (Robinson[98]). For bright colours with a shorter brightness range between the solid and white paper, fewer divisions will be discriminable than for black ink or dark colours. Hue or texture differences should be added if more divisions in a series are required. It is not entirely clear whether these recommendations are applicable to tint screens requiring absolute identification. It has been shown in non-cartographic contexts that the number of absolutely identifiable colours increases with practice (Hanes and Rhoades[591]) and it is conceivable that as many as eight tint screens could be identified reliably with sufficient training. However, for most practical purposes with relatively inexperienced observers it probably would be unwise to expect perfect performance on an identification task with a non-redundant code of eight tint screens. Bishop and Crook[592] recommended only three luminance (Value) differences for reliable identification of a given hue in an operational setting. With the exception of hypsometric tints, which do not require absolute identification, more than three value differences in the same hue are rarely found on topographical maps and aeronautical charts. Other sources recommend four brightness intervals for non-redundant coding under good viewing conditions and two intervals when viewing conditions are below optimum (Van Cott and Kinkade[599]; Potash[535]).

Absolute identification of value differences is made more difficult on maps by induced brightness contrast effects of adjacent coloured areas which change the perception of value of a given tint screen. Robinson and Sale[95] demonstrated the apparent "waviness" of a series of tint screens arranged in a row side by side: each contrast boundary was perceptually exaggerated with the lighter area appearing lighter and the darker area appearing darker for a small distance either side of the boundary. As reported in Chapter 3a this effect can be interpreted in terms of lateral inhibitory and excitatory processes at neural units connected to the receptors in the eye. Although the "waviness" of series of tint screens can be easily demonstrated when the tint screens are of equal area and arranged in a row in order as on a map legend, the effect is not so apparent on maps where the arrangements are complex and where the area sizes are irregular. On the other hand, the effect of induced brightness contrast on small areas with darker or lighter surrounds can be pronounced for both regular and irregular shapes: a given tint screen will appear lighter against a dark surround and darker against a light surround (e.g. Robinson and Sale[95], p.258). This undoubtedly increases the difficulty of identifying print screens, particularly when the differences between individual screens are near the threshold for discrimination.

Chroma Differences

Chroma or saturation differences are not normally systematically varied on maps independently of hue and value differences. Screen tints and the addition of grey to coloured areas affect both the value and chroma of coloured areas. Variations in the strength of printing inks affect both the chroma and value of the colour. Whereas, Robinson and Sale[95] described chroma as the least significant of the perceptual dimensions of colour in map design, Cuff[600] showed that differences in chroma may interfere with the ability of observers to utilise symbols scaled in graded series by value differences. The importance of controlling for chroma differences often seems to be under-estimated.

Colours with high chroma or saturation and high brightness contrast tend to be used for coding point or line features. The relationship between symbol size and chroma was discussed by Keates[120]. He pointed out that a small area of a given hue will appear less saturated than a larger area. For this reason, high chroma inks are considered to be essential for coding small symbols if their hues are to be perceived. Whereas saturated, high chroma hues are used for coding fine detail, the same colours may be unacceptable over a large area of the map, such as for coding woodland, because the effect may be visually overpowering, creating an imbalance (Keates[120]). Desaturated hues tend to be used for symbols that require de-emphasis or that cover large areas of the map. On maps portraying quantitative data, high chroma is normally associated with high magnitude, and low chroma with low magnitude.

Bishop and Crook[592] recommended the use of only two chroma differences (30% and 70% purity) for identification tasks with sets of colours differing in Hue, Value and Chroma. But Robinson[98] and Keates[120] both pointed out that the discriminability of Chroma differences varies with the Hue and Value of the colour. Some Hues can be printed with more discriminable variations in Chroma than others. Fewer differences in Chroma can be discriminated at low and high Values than at intermediate Values. This is illustrated by the Munsell Book of Colour which shows that printed samples of the perceived colour space occupy a solid similar in shape to two cones joined at the base, rather than a cylinder of constant diameter.

Hue Differences

The employment of hues on maps is largely governed by the requirements of convention and standardisation. The US Army Field Manual 21–31, reported by Potash[535], lists the following conventions:

(1) Black for the majority of cultural or man-made features.
(2) Blue for hydrographic features such as lakes, rivers and swamps.
(3) Green for vegetation such as woods, orchards and vineyards.
(4) Brown for all relief features, such as contours.
(5) Red for main roads, built-up areas, and special features.

On aeronautical charts, electric blue, a purplish-blue, is usually employed for coding air information.

Robinson[98] reported the following conventions:

(1) Red is associated with warm and blue with cool temperatures, such as in the representation of climates or ocean currents.

(2) Yellow and tan are associated with dryness and paucity of vegetation.

(3) On maps showing positive and negative values red usually represents positive and blue negative.

Both Keates[120] and Robinson and Sale[95] referred to the established spectral progression of colours for layer tinting of elevations: blue for water, green for lowlands, and yellows through browns to reds for progressively higher relief.

Hues have conventional applications in coding visual displays other than maps. According to NATO Military Standardisation Agreement 3370 red should be used as a warning signal, and yellow or amber denote warning or caution. Green, white and blue are normally advisory signals: green denotes safety, that the condition is satisfactory, or within the tolerance limits; white or blue indicate status without implying safe or unsafe conditions. The use on some aviation maps of red for coding obstructions, danger areas and power transmission lines conforms with this standard.

The connotative and subjective aspects of hue have received some recognition in cartography, although cultural differences mean that these have limited applicability to aviation maps with multi-national, world-wide usage. Hues are described as warm (e.g. red), cold (e.g. blue) and neutral (e.g. brown) referring to associations with mood rather than temperature.

Another factor concerns the apparent advance and retreat of hues or their apparent distances. Under controlled conditions it is possible to demonstrate that some coloured surfaces appear to be nearer to or farther from the eye than they actually are. Taylor and Sumner[601] and Johns and Sumner[602] experimentally demonstrated that red appeared nearest to the eye, followed by white, yellow, green, blue and black. The authors found a high correlation between distance and brightness. Robinson[98] suggested that this effect may be due to chromatic aberration of different wavelengths causing reds to be focussed nearer the lens than blue. It is tempting to suggest that this effect may have some usefulness in separating information into visual planes on maps, but there is no empirical evidence to confirm that it has any effect on map reading performance.

On the discriminability of non-redundant hues, it is normally estimated that 9 or 10 hues can be reliably identified in visual displays with little training. Halsey and Chapanis[603] found that 10 to 12 spectral colours could be distinguished to nearly 100% accuracy. Conover[604] and Conover and Kraft[576] used Munsell colour samples and concluded that not more than eight maximally saturated surface colours can be identified by most subjects. For operational environments they considered that a more realistic figure would be within the range of five to seven. Baker and Grether[605] concluded that nine hues was a practical number. The ability to remember hues is a limiting factor on the number of colours that can be reliably identified. Practice improves performance on colour identification (Hanes and Rhoades[591]). Size (visual angle) is an important factor; large areas of colour are easier to identify than smaller areas. The colour of the illuminant and the integrity of colour vision of the observer are additional factors. Morgan et al.[74] reported a set of nine surface colours, including black, grey and white, that can be identified reliably by colour-normal and colour-blind observers. There is little empirical evidence that directly bears on the number of hues that can be reliably identified on maps. In practice, partly for economic reasons, most topographical maps are printed in between 6–12 hues, which is within the limits suggested by the human factors literature. Map hues differ in that they are usually combined with other coding dimensions, such as shape, and actual hues chosen are rarely checked for discriminability.

Simultaneous colour contrast effects leading to the induction of the complementary colour of the surround were regarded by Robinson[98] as reducing the ability to match hues on maps. Attempts to demonstrate this effect in a map-like context have been unsuccessful (Audley et al.[189]). Induction may only be a problem when large numbers of colours are used with small differences between them. Robinson[606] suggested that induced contrast effects are largely eliminated if the coloured areas are outlined in black.

In addition to the requirements of convention, the selection of hues for maps is determined by the need to achieve adequate contrasts for line detail. Hues with a clear contrast against white backgrounds, such as brown and blue, are used for point and line symbols. Hues which give good contrast for overprinted detail printed in black, blue and brown, such as yellow and green, are used for coding area features such as hypsometric layer tints and vegetation. The requirements for visual organisation and balance, discussed separately in section 8f, also influence the choice of hues on maps.

8e INFORMATION DENSITY AND CARTOGRAPHIC GENERALISATION

Maps are reduced representations of geographical surfaces (Keates[120]). In technical drawing, the scale of representation may be 1:1 or an enlargement, but in mapping, the surface to be represented is so large that reduction is essential to achieve effective communication. Unmodified reduction increases the density of information per unit area. Aerial photographs are unmodified reductions of geographical surfaces and they demonstrate well the consequences of reduction without alteration: the dimensions of linear and area features are reduced in the ratio of the reduction; intricacies

and detail are increased in the same proportion; the distance between features decreases, while crowding and clutter increases; clarity and ability to detect, recognise and identify features are reduced. Whereas optical magnification and annotation (Hill[309]; [506]) are often necessary to extract information from aerial photographs, various graphic devices, known as cartographic generalisation, are used in cartography to modify the representation and render the reduced image effective as a means of communication.

The principles of cartographic generalisation are discussed by Robinson and Sale[95]; (pp.52–61), and by Keates[120]; (pp.23–28). Robinson and Sale[95] drew a distinction between the elements and controls of cartographic generalisation. The elements of generalisation – simplification, symbolisation, classification, induction – are employed by the cartographer according to the requirements dictated by the controls: the objective or purpose of the map; the scale of the representation; the graphic limits or capabilities of the communication system; the quality of the data, its reliability and precision. The authors added the corollary that in practice the four elements of generalisation are not clearly separated so that, for instance, the processes of selection and elimination of information during simplification overlap with characterising by symbolisation. Keates[120] distinguished between the generalisation of locational information and meaning on maps. He discussed selection simplification and combination together, separated them from classification, and included exaggeration and displacement.

Simplification

The process of simplification refers to the selection, elimination and combination of information, and its re-arrangement, reshaping, exaggeration and displacement. All these devices are intended to achieve effective communication with reductions in the scale of the map and the space available for representation.

A great deal of information, particularly on small scale maps, is omitted, and a selection is made on the basis of importance. This applies for example to drainage systems which appear as progressively simpler patterns as scale is reduced. A further procedure is to combine similar items. A large scale map may show most individual dwellings, whereas a small scale map will depict only large groups of dwellings. Simplification means a considerable loss of detail; on small scale maps, bends in streams, indentations in coastlines, irregularities on contours, windings of minor roads, etc., are fewer and smoother, and do not retain their angularity when scaled down. As part of simplification, some areas are replaced by points: town fill is changed to a symbol, and shape information is lost. Similar items are congregated together: a group of small hillocks may appear as a broader hill, or a region with many small woods may be depicted as generally afforested. One problem with simplification is that part of the significance of many individual features comes from their juxtaposition with others. A settlement beside a river may be located where the river is bridged; a railway station in a remote region may be where there is access by road; terrain and drainage systems are causally related. If it is contended that only certain of these features have any operational significance and need to be shown on the map, much of their meaning may be lost or distorted wherever it depends on information not portrayed. As scale is reduced, the dimensions of symbols remain physically constant or nearly so, in accordance with legibility requirements. Thus, it may be impossible on small scale maps to depict an industrialised valley in a mountainous region without deliberately exaggerating the width of the valley to accommodate on the map the cartographic symbols for a river, railway, road(s), and built-up areas needed to avoid misrepresentation. Contours may, as a result, have to be displaced, leading to an exaggerated depiction of the steepness of the valley sides. Another source of exaggeration associated with small scale maps is that, because symbols and lines must remain large enough to be legible, the features depicted by them on small scale maps extend over regions which they do not in fact occupy. This entails some loss of accuracy regarding their precise location.

Symbolisation

Symbolisation can be regarded as a form of generalisation whereby concepts, facts and the essential characteristics, comparative significance and relative position of geographical distributions are graphically summarised and coded. The degree of generalisation in symbolisation may be comparatively small, as when representing administrative boundaries by a set of symbols, or it may be high, such as when adjacent towns are symbolised by a single dot on a small scale map. Generalisation by symbolisation increases with decreasing scale, but it also varies within a given map. The portrayal of the fundamental characteristics of coasts and rivers by generalised symbology cannot be achieved by simplification and smoothing of the line elements alone. Too much simplification may render the representation unrecognisable. In symbolising the feature, the designer seeks to identify the essential characteristics of the feature that distinguish it from others, and while simplifying and smoothing the line elements in accordance with the scale requirements, he will also attempt to preserve the distinctive elements if necessary by selective exaggeration and emphasis.

Classification

Classification in cartography has been discussed in Chapter 8b. The ordering, scaling or grouping of phenomena into classes is a characteristic of human information processing. In cartography, it is also a part of the process of generalisation. Generalisation by classification has the effect of reducing the number of distinctions portrayed by classes and sub-classes of cartographic information. As the scale is reduced, the number of road classifications may be reduced, and tracks and paths omitted altogether. This cannot simply be a matter of showing only all major roads, because then a region with only a few main through roads and no minor roads would be depicted in the same way as a region with a similar number of main roads and a complex network of numerous minor roads. Similarly, many small

adjacent lakes must remain distinguishable from one large one, and a region with numerous small streams should not be indistinguishable from one with no visible drainage at all. Successful generalisation by classification depends on starting with much more detailed information, and deriving the general classes from the specific. It also depends on understanding the geographical region and trying to convey its characteristics, if necessary by some departure from strict accuracy, so that two regions, quite different on geographical content, cannot appear very similar when mapped, as a result of unintelligent generalisation.

It would seem to follow that successful generalisation by classification must depend on the exercise of some cartographic discretion to fit particular circumstances. This tends to conflict with the need for a very precise specification for a world-wide map series involving many cartographers. This dilemma is not easily resolved, particularly when, given discretion, cartographers tend to generalise so that they fill but do not over fill the space available. The result is that desert regions show too much, and regions with very numerous features tend to show too few of them, a critical comment noted by Keates[120], echoing that of Wright[16] who emphasised that for aviation the use of inconsistent generalisation can be highly misleading.

Induction

Robinson and Sale[95] described inductive generalisation as the process of making logical inferences from data based on accepted associations whereby the cartographer portrays more information than has been surveyed. This specialised form of generalisation applies particularly to thematic mapping where isarithms for instance, are constructed from discrete data points. On topographical maps generalisation by induction is involved in the representation of relief by contours.

Empirical Research

Empirical data directly concerning the process of map generalisation in relation to information density are scant. The generalisation of cartographic information when reducing the scale of representation is a practical necessity. Yet, it seems that little experimental work has been done to verify that the procedures used are the most appropriate or to identify those parameters of generalisation that affect map reading performance.

Cartographic research on generalisation has been mainly concerned with methods for quantifying existing generalisation procedures. Topfer and Pillewizer[607] formulated the law or principle of generalisation, known as the Radical Law or the Principle of Selection, which concerns the number of items that can be expected to be found on a newly compiled map at a given scale as compared to the number on the source map. It is expressed in its simplest form as:

$$n_f = n_a \sqrt{M_a/M_f}$$

where n_f is the number (n) of items on the newly compiled map (f)

n_a is the number of items on a source map (a)

M_a is the scale denominator of the source map

M_f is the scale denominator of the newly compiled map.

Broadly stated, since the reduction of area on a map takes place as the square of the ratio of the difference in linear scales, the amount of information that can be shown per unit area decreases in geometrical progression.

Sukhov[475] applied Information Theory to analyse the content of maps at different scales. Formulae were presented for estimating the information losses incurred from generalisation. Several comparisons were made to illustrate the method including a comparison of the information loading of an Atlas (71.8 bits per 1 cm^2) and a book (31.0 bits per 1 cm of a line of text). Measurements showed that despite considerable generalisation, information loading per unit area tended to increase as map scale was reduced. Srnka[476] attempted to quantify the principles of selection of information in cartographic generalisation by expressing information quantity by the number of elements or the length of lines per unit area. More recently, Vanicek and Woolnough[608] and Beckett[609] have presented mathematical formulations concerning the generalisation of linear data, the former relating to digitised methods for automated cartography, the latter relating to the corrections required when measuring lengths of line features on maps at different scales.

With the exception of Sukhov[475], quantitative methods reported in the cartographic literature have tended to be concerned with the physical description of the graphic elements rather than with their perceived numerosity or complexity. Fragmentation of the map content into elements fails to take account of the information that arises out of the unity, wholeness and structural properties of map contents. More complex quantification techniques that account for the continuity and wholeness of linear information and that could be applied to maps have been proposed elsewhere by MacKay[610], Freeman[611] and Leeuwenberg[612,613]. Experiments on the subjective complexity of lines and patterns show a considerable discrepancy between measured and perceived estimates of complexity or numerosity (Payne[614]; Cabe[615]; Krueger[616]). Judgements of visual complexity may be made according to different principles by different people (Payne[614]). Fairly consistently, the number of symbols scattered on a surface is judged to be less than it really is, and the closer the symbols are bunched the more pronounced this misjudgement becomes (Krueger[616]).

The effects of information density on target detection have been studied in a variety of applied and experimental contexts. It has generally been found that as the density of elements in the visual field increases the time to search for and identify an object increases monotonically. However, the relationship between information density and target detection with multi-attribute stimuli is more complex and the injection of structural factors possessed by maps severely restricts generalisations from studies using other visual fields.

The precise shape of the search/density function is disputed, it being either linear or logarithmic. Landis et al.[193] found that with maps the curve is J-shaped. This is shown to be due to an interaction between colour coding and density; where density is low, colour facilitates search time and where density is high the advantage of colour is lost. Colour is utilised in search to structure the visual field and reduce the area of search.

The effects of information density on map reading performance are task dependent. Lichte et al.[57] examined the effects of chart scale and amount of information on aiming point identification in a scope reading task, but failed to find significant differences between low, medium and high information charts probably because these distinctions only related to the general density of information and not to differences in information relevant to the task. Christner and Ray[103] showed that increases in the total number of targets on a map have different effects on performance with different tasks. Under certain conditions, with counting and verifying tasks, performance tended to improve as the total number of targets increased, because increased density permitted the subjects to deal with groups of targets rather than single targets. Taylor and Hopkin[151] found that the density of cartographic information did not significantly affect the speech and accuracy of plotting grid references. However, greater density of cartographic information around a pinpoint led to greater accuracy and less time in locating the pinpoint from topographical descriptions of its position. Information Theory (Garner[617]), Signal Detection Theory (Swets[618]) and Stimulus Sampling Theory (Neimark and Estes[619]) have been related to search data on 'pseudo' maps by Hany and Shaw[224].

Pattern recognition and pattern matching studies are relevant to tasks involving the comparisons between maps and the ground or other collateral material. Bush et al.[217] presented subjects with patterns from filled and unfilled hexagonal cell matrices and required them to match four comparison patterns varying in complexity with a standard. Four physical measures were used to predict matching performance-pattern length, two metrics of pattern density, and a measure of the difference between the comparison and the standard. The results showed that the difference measure was the most highly correlated with response time; responses were quicker when the standard pattern was less complex than the comparison than when the standard pattern was more complex than the comparison. These results suggest that when a particular location or pattern (standard) is being sought in a dynamic visual field (comparison), that is, the view of the ground outside the cockpit or on a sensor display, then generalised briefing aids such as maps will make better 'standards' than say aerial photographs which are at least as complex as the comparison scene. The studies by Hill[309,516]) on comparative assessments of line maps and orthophotomaps, by Barratt et al.[345] on radar map matching, and by McKechnie[437] on radar interpretation support this conclusion. Research is needed to determine optimum levels of generalisation for matching tasks. However, knowledge of human perceptual processes, of the Gestalt laws, and of the effects of relevant and irrelevant information, suggests that maps designed and generalised to emphasise the most salient and distinctive visual characteristics of the topographical surface, omitting irrelevant detail, should lead to superior detection, recognition and identification performance.

8f VISUAL INTERACTION AND BALANCE

Design in graphics can be defined as the orderly arrangement of the parts to a harmonious whole (Yanosky[574]). In cartographic design, the map is regarded as a visual composition requiring planning, organisation and structure just like a written paper (Robinson[606]; p.55). With maps the fundamental shapes and their locations are predetermined. Borders, legends, and titles can be arranged in accordance with aesthetics, so that they "look right", balanced around the "optical centre" of the map, a point usually defined as about 5% above the centre of the bounding shape or border of the map (Robinson and Sale[95]; p.264). The arrangement of topographical features of pre-determined location and shape is restricted to an imaginary third visual dimension of visual importance, prominence or salience. Here, the information is assigned to visual planes and the organisational hierarchy or balance of emphasis is arranged according to the functional importance of the feature: the more important the feature, the greater is its visual emphasis and the "higher" is its visual plane.

Efforts to achieve better visual balance and appearance have led to an increasing emphasis on the map as a whole, rather than on the design of its component symbols. McCleary[503] noted the difficulty of applying refined psychophysical measurements to study the whole map, and Heath[147] remarked that the simultaneous presentation of many principles of visual design on a map reduced the impact and effectiveness of each one. It can also lead to difficulties in designing sub-categories of information. Cues of visual depth such as overlapping areas can be used to try and assign items of map information to different visual layers,(Wood[188]), although the interacting effects of maps make this effect difficult to achieve. Furthermore, relative changes in the functional significance of a symbol, associated with differences in the background information, may ultimately conflict with this principle of visual planes in two ways. One conflict is that, for information in close geographical proximity, it may be necessary to try and show it in the same visual plane so that all the information is perceived at once as functionally related. Yet to do so implies that the related information must be portrayed with more similar visual dominance than it might otherwise have, so that the individual items of related information are not optimally discriminable from each other. The second conflict is that in theory any given cartographic

category – bridge, minor road, power transmission line, etc – should be in the same visual plane throughout, being portrayed in the same way. In practice, the dominance of a given symbol will be a function of the context in which it is presented, a point that is particularly relevant to aeronautical charts exhibiting wide variations across different geographical regions. Power transmission lines, for instance may be visually on a dominant plane in a relatively featureless region, but they would lose much of their visual impact in a region of concentrated artificial features, where operationally they may remain just as significant. This raises the question of whether the effects of visual interaction and the requirements for balance justify progressive changes in the psychophysical properties of a symbol, such as weight or colour saturation, so that the relative visual dominance of a given feature is retained as its surroundings change, and the flexibility in showing functional relatedness (or lack of functional relationship) is increased between geographically proximal features. The desired flexibility in specifying figure-ground ratios for optimum spatial structures, such as the range of 1:2.18 to 1:3.56 given by Crawford[620], has not been studied.

Some of the methods for achieving emphasis and for changing visual interactions on maps were outlined by Saunders[621], who subsequently described in more detail the control of colour (Saunders[622]) in achieving desired cartographic effects. These effects included not only legibility, balance, colour sensitivity, and the apparent visual distances of colours, but also more subjective aspects such as its aesthetic qualities, its attention-getting aspects, and connotations of meaning. Dent[556] described and illustrated a variety of techniques used in cartographic design to produce an organised visual hierarchy among the map elements, including contrast variation, edge fuzziness or gradient, overlay and texture.

It is important that considerations of visual interaction and balance are borne in mind throughout the evolution of the map specification. In particular, decisions on what the map contents should be can lead to insuperable difficulties in their portrayal if they are not considered in terms of their total quantity, visual impact, clutter, visual separability, and scale. The choice of map symbols must take into account the compatibility of all the symbols, particularly those for related features. Siebert and Dornbach[623] noted that layer tints and hill shading should not be decided in isolation, but should be seen to be compatible with other features, such as drainage.

Sometimes in aviation, the requirements of the users clash with traditional cartographic practices in a way which affects visual balance most of all. For example, it is normal in a topographical map to present the artificial features as the foreground, with the background formed by terrain features: this is logical since the latter are everywhere and the former are not. However, on certain aviation maps used in low level flight the terrain *is* the most important information and logically should be depicted as the foreground and as more prominent. Also, on most topographical maps linear features are visually dominant because of their linearity and because their functional significance requires this to be the case. But in aviation maps point symbols, such as those for obstructions, may be of greater significance, but cannot be made more prominent visually without emphasising them so much that their size or weight obscure other information and lead to a reduction in the accuracy of their location.

A principle which has to be followed in the interests of balance is to portray the information of least importance with the minimum sizes, weights, and contrasts necessary to ensure legibility at the intended viewing distances. The reason is that this information determines the level of emphasis to be assigned to everything else. Thus, the lower it is, the less clutter there will be, the greater the lightness and reflectance of the whole map, the greater the range between the most and least dominant, the more flexibility in the use of contrast and in trying to derive various visual planes, and the less competitiveness among the most dominant information. A tendency which the cartographer has to guard against is his propensity, if a symbol has inadequate contrast, to remedy this by making the symbol darker, rather than by making the background lighter. A further argument in favour of minimising the dominance of the least important information is that ultimately it aids the effective portrayal of the most important point information by reserving exclusively for it the major contrasts available, particularly those employing saturated hues. Many of these principles of balance are discussed more fully by Keates[120].

Interaction and balance are greatly influenced by many advances in map display technology. The conservatism of cartographers may effectively question new conventions until they have been proved, but may also mean that maps are slow to adapt to changing needs. This characteristic, recognised by Wright[16], has since become more pertinent. Many of the techniques described by Honick[624] in the production of maps for moving map displays imply distortions of visual balance. So do techniques such as removing information and enhancing hill shading or emphasising ridge lines to improve radar map matching (Barratt et al.[345]). Adding information to an orthophotomap (Smith[165]) cannot normally replicate the visual balance of a conventional map, and would probably not be successful if it could. There is a tendency to tackle the considerable cartographic design problems generated by numerous display requirements by emphasising the level of symbol design to attain cartographic legibility rather than by viewing the map as a whole with its requirements for visual balance and selective contrast. Much of this emphasis is caused by the practical need to devise legible symbology to obtain usable maps, coupled with a strictly limited time-scale for doing so. Longer term solutions require that a satisfactory solution to the problem of visual balance must be found afresh for each new display type, using the same considerations and techniques as for conventional maps to achieve an acceptable balance and visual appearance.

Sadly, it seems that the human factors literature has little to offer that is directly relevant to the structural problems of map design. Although various principles pertinent to visual interaction and balance, such as visual structuring, figure-ground relationships, visual scanning, and selective attention, have been extensively studied in the human factors literature, the purpose has been to reveal and explain the mechanisms involved, and the findings suggest factors which could be relevant to maps rather than explain exactly how they are relevant to maps. Their direct practical value in map design

is therefore somewhat limited, to the extent that the applicability of the principles to maps may be debatable, and the form which they take in maps may be unclear. Psychological experiments on perceptual structuring do not deal with concepts as complex as visual balance in topographical maps, or as receding planes within a map (Wood[188]). Figure-ground studies tend to deal literally with figure and ground, that is visual structuring into two planes. Practical guidance on design for visual structuring into more than two planes, or on sub-dividing the visual structure within the figure or the ground is not available.

The principles of perceptual organisation described by Easterby[96] as applicable to static displays should be relevant to paper maps, particularly in regard to the relationships between meaning and structure. How far maps can be designed to overcome the propensity, while searching, to decode irrelevant material (Landis et al.[193]), has not been stated in psychological terms. Dodwell's[625] model of perceptual clarity, which suggests that some form of autocorrelation is involved as an aid in sequential processing, has not been examined in relation to maps. These, and other principles described in the literature, are examples of perceptual frameworks or display principles which could be considered in relation to maps. If they provided effective guidelines, then the rationales for cartographic practices and for perceptual principles would both be strengthened. If they failed to do so, then the limitations of the claimed principles would be revealed, and the understanding of some limitations imposed in achieving visual interaction and balance would be enhanced.

The extent to which principles of map portrayal and structuring can be employed to guide visual search remains unknown, but evidence from other complex visual material suggests that searching can be intelligent in relation to its aims. Items which are not informative may not be fixated, being discarded as part of a scanning process. Items which are unusual or unpredictable may draw the gaze, and items which are recognisable but redundant may not be the subject of fixations (Mackworth and Morandi[233]). The applicability to maps of such findings should be tested, and their consequences for map design explored. They reveal some potential for controlling map use by map design.

CHAPTER 9

HUMAN FACTORS DATA APPLIED TO CATEGORIES OF CARTOGRAPHIC INFORMATION

Optimum design solutions to information display problems are desirable from a human factors point of view, but there is rarely a single optimum solution to the problem of how a particular cartographic information category should be portrayed. Factors such as geographical location, map information content and density, map scale, the demands of different tasks, different display media, and different physical environments for map usage all can be sufficiently important to change the method of portrayal which must be adopted to satisfy particular operational needs. On world-wide series and on multi-purpose maps the symbols used can rarely be optimum for all map sheets and all applications. Therefore in applying human factors data and principles to ensure the effective portrayal of cartographic information, it is necessary both to assume that different circumstances may produce different design solutions, and to ensure that if there are different solutions these must not be a source of confusion, misreadings or illogicality. In practice, this means that while there may not be a single convention for portraying woodland, for example, different representations must nevertheless all be sufficiently similar and logically related to be recognisable as indicating woodland, none should be interpretable as depicting an unrelated information category, and no symbols for features other than woodland should be so similar to woodland symbols as to be erroneously interpreted as meaning the same. Ideally, this should remain true whatever restrictions on coding are imposed by such factors as map content, map illumination, black and white displays, or poor image resolution. When there are many restrictions on coding, the consequent human factors problems in finding the optimum method of portrayal on a given map may become insuperable, though it nevertheless remains possible to obtain an adequate portrayal and to effect improvements by following human factors principles.

Various kinds of evidence support the view that the optimum map design for one usage may be far from optimum for others. Osterhoff and McGrath[133] showed that the relative navigation performance with various maps was route dependent, and they concluded that the relative effectiveness of different maps varied with the type of terrain. Phillips et al.[267] compared four relief maps, and showed that no single one was best for all users, but that the choice of map greatly influenced the users' performance. Special requirements for portrayal of terrain may be introduced by computer maps (Breme[626]), by orthophotomaps (Hill[309,516]), by three dimensional maps (Jenks et al.[627]) and by examining maps stereoscopically (Gamezo and Rubakhin[628]). Taylor[100] identified the particular design requirements of maps for moving map displays, whereas Barratt et al.[345] showed how these might differ when the map image was combined with radar. The application of human factors principles to aid portrayal normally requires some empirical verification of validity. This is not a substitute for job analysis or for user opinion but an essential addition to them, particularly when many uses are envisaged for a map (Hopkin[70]), and the conflicting requirements make it difficult to evolve a satisfactory specification (Bennett et al.[114]).

Information on the relative importance of classes of cartographic information for different operational tasks, essential for determining the relative emphasis required by users, can be obtained from the following sources:

(1) Helicopter Operations: Wright and Pauley[349] – Discussion of the importance of features for helicopter low level tactical maps: Barnard et al. – Ratings of the usefulness of features for helicopter day transit, day nap-of-the-earth and night operations compared with how well they are shown on existing 1:50,000 series.

(2) Low Altitude, High Speed Flight: McGrath and Borden[121] – Ratings of the visual utility of features for checkpoints judged from films compared with the selection rate and ratings of the cartographic utility judged from 1:500,000 and 1:1,000,000 scale maps: Murrell[131] – Proportions of features selected by aircrew for a special purpose 1:250,000 scale map together with ratings of the importance of decisions to include the features: Lakin[340] – Rank orders of importance of features for inclusion on a 1:250,000 scale map for flight planning purposes and for in-flight use.

(3) Night Operations: Taylor[348] – Ratings of the importance of features for fixing positions during visual night flights en route at low altitude in helicopter, transport and jet aircraft.

9a NATURAL FEATURES

Relief

Among natural features, the portrayal of relief has received most attention and experimentation. Numerous methods of portrayal have been developed including spot heights, contours, layer tints, shading, hachuring, perspective drawings, and planimetrically correct pictorial representations. Methods of portrayal have to bear a logical relationship to some classification of land forms or terrain. In one example of the use of sampling theory in delineating land forms

(Wood and Snell[629], quantitatively described landform regions proved to be similar to qualitative descriptions of the same regions, when the quantification and grouping into regions was obtained by weighting six terrain factors, namely average slope, grain, average elevation, slope direction changes, relief, and ratio of elevation to relief. The aspects of terrain which have to be adequately portrayed for aviation purposes can be derived from task analysis, from which the way in which the map should be used can be stated, for instance, to obtain relative or absolute height information, or both. Symbology can then be selected to encourage its correct usage, and a classification of terrain suitable for the envisaged tasks can be derived (Sherman[431]). Conventions used in portrayal can indicate the importance of the distinctions being made, so that the visual prominence of a feature on the map is associated with its prominence from the air (Chichester[17]). Whereas some guidelines can be proposed for the portrayal of terrain using various individual conventions – hypsometric tints, contour lines, hill shading, spot heights, maximum terrain elevations, etc – their successful integration into a coherent visual entity has been inadequately researched. In many respects, the portrayal of relief remains a creative task, involving intuitive judgements of balance and emphasis and a striving for three-dimensional pictorial quality rather than randomised representations of two dimensional features (Robinson and Sale[95]).

Phillips et al.[267] compared spot heights, layer tints and hill shading on objective tests of legibility but did not test their interactions. Spot elevations were good for judgements of relative or absolute heights but poor for landform visualisation; contours were not particularly good for any interpretation task; hill shading produced good visualisation when added to contours; layer tints were good for visualisation and for judging relative heights, but they were poor for estimating absolute heights because of the difficulty of matching the colours on the map with the legend. Shaw and Maclagen[630] compared contour lines with layer tints, for geochemical and topographical data. Layer tints were favoured for geochemical data, which was more complex, and contours for topographical data which was more suitable for demonstrating map structure. Methods for teaching the interpretation of contours have been studied by McGuigan[631] and Ling Chu Poh[632].

On aviation maps, some subjective assessments have been obtained on the relative merits of different methods of relief portrayal (e.g. Lakin[633,340]; Anon[507]; Taylor[222]) but these must be treated with caution as they are likely to reflect personal prejudices as well as legibility criteria. The notion that the total image of the terrain should be planned to convey the experience of structure and order was explored by Siebert and Dornbach[623], who discussed layer tints in conjunction with hill shading, and concluded that shading conveyed ambiguous depth information, was incompatible with layer tints, and must be light if used at all. For aviation maps, they preferred layers to shading, as being schematic rather than pictorial and therefore more compatible with the map treated as an information system rather than as a picture. In contemporary studies, Freer[154] described an experimental aeronautical plotting chart depicting terrain by layer tints and spot heights only, and Williams[634] compared the use of tints alone with the pictorial relief effects which could be achieved by combining colour and shading.

Methods for portraying relief have been reviewed by Carmichael[635]; Imhof[636,637]; Keates[638,120]; Robinson and Sale[95] and Monkhouse and Wilkinson[139]. Robinson and Sale[95] differentiated between relief representation at large and small scales. They argued that at large scales, the designer is concerned with representing the three major elements of relief – slope, elevation or height, and shape – by contouring, hachuring and shading. At small scales, the generalisation is such that only the basic shapes and the important slopes and heights may be shown. Layering between selected generalised contours is more common on small scale maps, detailed hachuring is less common, and the essential characteristics of regions are sometimes shown, such as flat plains, tablelands, and low mountains by area symbols, usually in colours, e.g. terrain characteristic tints (Dornbach[127]) are shown on the 1:1,000,000 Operational Navigation Chart (ONC).

Keates[120] contended that relief has two main elements: elevation and slope. The shape or form of the surface is determined by both the elevation and slope. Elevation is represented by spot heights, contours and layer tints; slope information may be derived from contours and layer tints, but it is represented directly by shading and hachuring (line shading). In combining these various techniques, the basic problem is to make the separate elements perceptible and yet in harmony with each other. The most common combined systems are contours with shading, and shading with layer tinting with or without contour lines. Combined with contours, shading tends to be used on the largest scales for representing the major relief forms not readily apparent from the contours, on medium scales for reinforcing the forms shown by contours, and on both large and medium scales to supplement contours by portraying forms that fall within the vertical interval. Combinations of hill shading and layer tinting are more common on small scale maps.

Keates pointed out that the two techniques are essentially incompatible in that value changes due to layer tinting tend to introduce apparent differences in the darkness of shading and hence steepness of slope. Layer systems based on the principle of "the higher the darker" are difficult to combine with shading in order to achieve adequate contrasts for steep slopes at high elevations where they are most common. According to this argument, the principle of "the lighter the higher" should be preferred in combination with shading. Smooth colour progressions are also preferred to minimise the interruption of the slope shading caused by the layer "steps". Shading affects the perception of layer tinting by making the layers look darker and hence higher or lower depending on the system, and by reducing the colour contrast between adjacent layers. For this reason, shading should be kept as light as possible. What represents an acceptable combination of layer contrasts and shading density is in practice a matter of design judgement.

Subjective data on aircrew preferences for 1:250,000 scale topographical maps supported the combination of layer tints with hill shading of moderate to low intensity, rather than hill shading without layers. Most of the research in this area has been concerned with relief representation on the Joint Operations Graphic (JOG) 1501-Air Series.

A questionnaire survey of user opinions on prototypes for the JOG (Anon[507]) showed that 81% of the aircrew respondents preferred a layered version with standard hill shading, whereas only 14% preferred the unlayered version with darker hill shading. Taylor[222] obtained subjective scaling measurements from aircrew on the suitability of eighteen 1:250,000 scale maps, including JOG prototypes, for low altitude high speed flight. Generally the pilots preferred maps with layer tints and hill shading to the same maps without layer tinting but with hill shading. They preferred maps with layer tints and without hill shading to the same maps without layer tints and with hill shading. It was also found that darkening hill shading did not make maps without layer tints more acceptable. With regard to relief portrayal on 1:250,000 scale maps, 72% of aircrew in Lakin's[633] sample considered contours essential, 46% considered layer tints essential, and only 10% considered hill shading essential.

Spot elevation were assumed by Lakin to be essential. In a later questionnaire study (Lakin[340]), 73% of aircrew indicated that they used contours rather than spot heights to obtain height information on 1:250,000 scale maps and the "flat appearance of layering" was judged to be the most serious of sixteen specified criticisms of the JOG series. During low altitude operations at night, Taylor[348] found that contours were used comparatively frequently by aircrew, but the actual contour values were referred to relatively infrequently, indicating that obtaining information from contours on the shape of the terrain rather than on its absolute elevation was probably more important. Relief shapes and profiles were rated more important than spot elevations for fixing positions.

Spot Elevations

The absolute height of selected points on aviation maps is shown by spot elevations. A principal function of spot elevations is to facilitate the calculation of minimum ground clearances and safety altitudes in flight. Consequently, to help this task they should not be shown indiscriminately, for instance on the sides of slopes or in flat areas. They should be selected to show the highest elevation of general areas irrespective of their visual prominence on the ground (critical spot elevations) and they should indicate prominent features that dominate the area, such as hills, tops, knolls, passes and saddles (normal spot elevations). The highest spot elevation on the sheet should also be shown, with special emphasis (e.g. boxed). Surface elevations of large lakes may be shown for calibrating radar. Maps vary in the success with which the selection of spot heights meets the requirements of the user. This is because only broad guidelines on their selection can be given and the choice of elevations is a matter of judgement by the cartographer.

Elevations are shown in feet on aviation maps because aircraft altitudes are normally calculated in feet. Aircraft altimeters display height in feet. It is important that the accuracy of spot elevations should be known to the user. Generally, it is sufficient to specify in the margin the limits of accuracy of the spot elevations (e.g. ± 100 feet). Spot elevation that do not meet these criteria (interpolated elevations) should be identified on the map by some form of visual coding (e.g. ± after the value). Variations in the size of the digits should be used to indicate different classes of elevation, such as between normal and critical heights. The most critical and least frequent should be in the largest size. Six or eight point type (Bold Copper Plate Gothic Italic; 1.52 to 1.78 mm) is used on the JOG for normal spot elevations, whereas twelve point type is used for critical elevations. Taylor[100] tested the legibility of spot elevations on the JOG under direct (paper map) and projected map display viewing conditions. He found that eight point type was adequate if shown in cleared boxes, but if contrasts were poor 10–12 point type was necessary for acceptable legibility at a normal (480 mm) viewing distance with no image magnification.

Boxing major elevations and clearing the background of detail is likely to increase conspicuity and reduce search time. By reducing clutter and maximising contrast, it is also likely to improve legibility, particularly with "the darker the higher" layer systems. Bridgman and Wade[639] found that boxing improves the readability of digits irrespective of the number, size and spacing. This is probably because it integrates the individual elements, similar in effect to the Gestalt principle of unity. For maps viewed at normal viewing distances, Taylor[100] recommended boxing snot heights and using bold colours to maintain adequate contrasts, medium stroke widths, medium to wide spacing, 1:1 height width rates, and upright, sans serif (Gothic) typefaces.

The location of spot elevations should be unambiguously indicated, preferably by a small dot close to and at a standardised orientation with respect to the digits (e.g. bottom left). The placement of the digits should also be guided by the need to avoid obscuring important local features and by the location that gives the highest contrast.

On most topographical aviation maps the importance of spot elevations has been reduced by the introduction of maximum terrain elevation figures (MTEFs) or, more recently, maximum elevation figures (MEFs). The latter include man-made obstructions located on top of hills, such as radio masts. These figures are normally shown for major grid quadrangles and centred within each area. Two digits are normally shown; one in a large typeface (42 point on JOG) to indicate thousands of feet ASL, and one in a smaller typeface (30 point on JOG) to indicate hundreds of feet ASL. Open face founts have been used to minimise clutter, but their legibility has been criticised by aircrew and they have been subsequently replaced by solid bold numbers on recent editions of the Series 1501-A Joint Operations Graphic.

Contours

Contours are lines of equal elevation that divide and classify the surface into a series of areas within intervals on a range of elevations. Like spot elevations, contour values are given in feet on aviation maps. Whereas each individual contour has a specific meaning indicating height above sea level, the primary function of contours is collective (Keates[120]).

More than one contour is necessary to determine the elevation of points not actually on contours. By their spacing and orientation on the map, they convey a visual impression of the form of the surface, indicating level areas by their infrequency or absence and showing steep slopes where they are close together. Perceiving the shape of relief from contours relies heavily on gestalt principles of perception and on the ability to integrate and utilise highly schematic cues.

The vertical interval between contours directly influences their effectiveness. Equal intervals on the same map are necessary in order to estimate spot elevations and to give a consistent impression of form and slope over different regions. Ideally, large contour intervals are preferable in areas with steep slopes in order to prevent clutter, and only small intervals to show relatively small variations in elevation in comparatively flat area. Selecting the most appropriate interval is particularly difficult with map series covering different regions of the world with large variations in the slope of terrain. The need to prevent clutter and obtain some separation between contours in mountainous regions means that most medium and large scale aviation maps use comparatively large contour intervals. As a result, in relatively flat areas the contours are widely separated and difficult to relate visually. Thus, standard contour intervals on aviation maps tend to give a poor representation of the form of the surface in nearly level or undulating terrain. In medium and high altitude flight, this is not an important problem. Here, the aviator flying VFR will be concerned only with major land-mark features. But in low altitude flight, quite small mounds and hillocks may be useful navigation features. Under operational conditions small hills and shallow valleys in otherwise flat terrain can give valuable cover against visual and radar detection. For these reasons, topographical maps intended for low-level navigation should be designed with a smaller interval between sea level and the first contour than between other contours. Also, accurate or imaginary supplementary (intermediary, auxiliary) contours coded differently (e.g. broken line) from standard contours should be added to show important, small, relief features that fall within the standard contour interval. This meets the user requirement for both types of terrain without creating unnecessary illusions of slope. In fact, there is evidence to suggest that visual exaggeration of relief features facilitates map reading with three-dimensional maps (Jenks and Caspall[225]). Knowledge of the perceptual processes involved in pattern recognition indicates that some exaggeration of critical features facilitates memorisation and subsequent recall and recognition. A false impression of slope can only be a serious problem if it leads the observer to expect a more shallow slope than in reality. Supplementary contours and reduced contour intervals will tend to give a "safe" impression of exaggerated slope.

Contours, like all line features, need to be coded in colours that contrast well with the map background. Most contours are shown in brown. High contrasts are particularly important for contours because their line widths are exceptionally thin compared with other line symbols. Index contours (0.2 mm on JOG), representing major elevations tend to be thicker than the standard line (0.1 mm on JOG) but substantially thicker line widths are undesirable because of clutter, particularly on steep slopes. Taylor[100] found evidence of poor legibility under normal viewing conditions for standard contour lines on the JOG and concluded that line widths of 0.2 mm were probably necessary to maintain legibility under critical viewing conditions. The legibility of contours tends to be poorest on layered maps with hill shading because of low contrasts. Where other information is dense, breaks in their continuity interfere with contour tracing. Interruption and elimination of contours is also common in built-up areas and it is sometimes necessary on the steepest slopes to achieve some visual separation. The fineness of contour lines means that they are difficult if not impossible to resolve in most projected and CRT map displays.

Contours are numbered on aviation maps partly to determine absolute elevations and partly to indicate the direction of slope. Other cues to slope can be used, such as streams and hill shading but these are not always reliable or available. The orientation of contour numbers should correspond with the reading direction of the observer. Whereas, on wall charts the alignment should be as near to the normal reading direction as possible (i.e. horizontal), on maps used in flight and normally oriented to track horizontal alignment is unnecessary and the numbers should be placed to read "up the slope". Thus, oriented to track inverted contour numbers will always indicate falling slope.

Contour numbers should be distributed on the map in accordance with the need to consult them. Frequent numbering causes unnecessary clutter. Isolated contours can be traced with comparative ease to determine their value. On close contour patterns, the value of a given contour can be determined by counting vertically from the nearest numbered contour. Therefore, contour numbers should be included in each major slope area, preferably on the index contour, or with a frequency commensurate with the ease of counting the lines. In areas with few contours, where counting vertically is more difficult because of the complexity of the pattern – individual contours frequently double back – most contours should be numbered, but the lateral distance between consecutive numbers can be large.

On the interpretation of contours by aircrew, McGrath[339] emphasises the importance of careful study during preflight planning. Contours are often shown in muted colours, he suggests, because they are designed primarily for preflight rather than in-flight study. In addition to indicating features of visual significance for the aviator, such as saddles, escarpments and valleys, contours should be used to identify areas of no radar return, sometimes interpreted as bodies of water, but due to shadows caused by relief obstructions. Estimates of the detectability of visual checkpoints at low level should be based partly on contour information. Supplementary or auxiliary contours should be given attention because they usually indicate relief features of particular land-mark significance. Pilots should also be aware of the fact that a small circular standard contour does not necessarily represent a good checkpoint feature; it may simply mean that the area within has risen slightly above or fallen below the contour value. Two concentric circular contours are a more reliable guide to the presence of a significant slope.

Layer Tints

The classification of the surfaces on small scale maps (1:250,000; 1:500,000) into hypsometric intervals coded by layer tints provides the map user with information on both the elevation and slope of relief. Two major design problems are normally associated with layer tints: the selection of the layer intervals, and the choice of layer colours. Although each layer tint represents a particular elevation interval and could in principle be identified on the map as having a specific meaning, the main requirement of layer tinting is to convey information on relative rather than absolute elevation and to emphasise elevation differences, e.g. basic shapes and patterns, relative highs and lows, ridges and valleys, hills and plains, (Taylor[402]). Decisions regarding layer intervals and colours are normally guided by this requirement.

Whereas contour intervals need to be constant on a given map to facilitate accurate interpretations of absolute elevations, the vertical interval for layer tints should vary in accordance with the operational significance of the elevation differences or changes. In flight at low altitudes, small changes in elevation are more important at low elevations than at high elevations and the method of representation should encode these differences. Intermediate or supplementary contours can be used to show small but operationally significant elevations, but layer tints with varying intervals achieve this more effectively without causing clutter and without seriously interfering with the representation of absolute elevations. Keates[120] distinguished four interval systems: equidistant, equidistant and supplementary, irregular, and progressive. Wright[363] recommended a geometric or cyclic linear progression of elevation intervals for low level maps so that high mountainous regions are divided into fewer classes containing a greater elevation range than relatively level, low lying areas. An equidistant interval scale would show few layer tint changes in areas of low ground and numerous changes on mountain slopes. Most topographical map series use progressive elevation intervals with an open-ended "greater than" . . . layer at the top of the scale. In a world-wide series, the mapping may be divided into major geographical regions of altitude range, with different progressive elevation intervals to facilitate the local interpretation of relative relief. Equidistant layer intervals are more likely to be used on large scale mapping (1:50,000; 1:25,000) of small areas, such as Approach Charts, where the range of elevations on a given sheet is comparatively small and where a given change has similar operational significance at all altitudes.

Keates[120] identified four problems relating to the selection of colours for layer tints:

(1) There is a need to design a progressive series of colours in which the steps are evenly balanced and perceptibly different for small areas without being overpowering for large areas.

(2) Elevation is a continuous dimension whereas the classification of the surface into layers introduces discrete steps and hence discontinuity. The greater the contrast between layers the greater will be the interruption of continuity.

(3) The colours chosen affect other symbols on the map, and should influence their design.

(4) Most of the cultural information on maps is in low lying regions and the layer system should be designed to minimise interference where other information is densest.

Irregular, spectral and value systems of layering were distinguished by Keates[120]. Irregular systems maximise chromatic and brightness contrast at the expense of visual continuity and progression. Spectral systems follow the spectral order of hues – blue, green, yellow, orange, red – for increasing elevations with no progression in brightness or value. Value systems order the hues on the basis of value, usually arranged as the "higher the darker" to maximise contrasts for cultural information at low level.

Miller et al.[42] favoured a logical gradation of hypsometric tints within a single hue for aviation maps. Crook et al.[40] and Taylor[402] recommended a single hue (green), value progression for layers on maps for use under red cockpit lighting. 1940 and 1950 series of 1:250,000 and 1:500,000 RAF topographical maps used value progression within a single hue (purple) for maps to be viewed under red illumination. Later UK series and the ICAO 1:1,000,000 World Aeronautical Chart used sepia, brown and buff tints, progressive in value but largely within the same hue. JOG, TPC and ONC series use a mixture of spectral and value systems. Bishop et al.[126] recommended using increasing densities of brown for relief on a helicopter pilotage map for marine assault operations, whereas Wright and Pauley[349] preferred a mixed spectral and value system similar to the JOG for Army helicopter low level navigation, because combined with hill shading this gave a more "pictorial" representation.

In a study of the mixed value and spectral elevation tint system used on the 1:250,000 Joint Operations Graphic, Hopkin[640] found that subjects had serious difficulty sorting samples of the layers into the correct order, and that they were unable to identify the tints reliably without confusion, even with prior knowledge of the scale. In a further series of experiments (Taylor[641]) comparisons were made of JOG layer tint scale and the progressive value system used on Ordnance Survey 1:250,000 Series. The results showed that the mixed spectral/value system produced inferior performance on a terrain profile matching task and on a task requiring subjects to identify relative highs and lows in ordered sequences of the layer colours. Another experiment showed that the efficiency of different value systems of layering using slightly different hues was dependent in part on the brightness range of the scale: scales with large brightness ranges and highly discriminable steps produced better performance than scales with small brightness ranges and moderately differentiated steps. Non-linearity of the chroma dimension at the transition between hues interfered with performance when non-additive printing techniques were used. It was suggested that additive printing of hues was preferable because it ensured linearity in chroma.

Kempf and Poock[508] showed that layer tints facilitated the determination of spot elevations but interfered with grid referencing performance. Significantly more time was taken to locate grid references on layered maps compared with unlayered maps. The range of brightness or value for a given layer tint system should be determined by minimum contrast required for overlayed information, such as spot elevations and grid notations. Taylor[642] recommended that the contrast difference between overprint and background should not fall below 45%, for overprint information coded in dark colours (blacks, blues) reflecting approximately 5% of the illumination.

Hill Shading

Hill shading uses variations of light and dark hues to create differences that give an exaggerated three-dimensional impression of the slope and form of the relief. On some maps, the perception of slope and form is augmented by textural cues provided by line shading or hachures. Hill shading is based on the principle that lighting a three-dimensional surface will produce different amounts of illumination on different slopes. The assumed illumination may be vertical or oblique. Vertical lighting maximises illumination on horizontal surfaces, leaving them white and unshaded. It minimises illumination on vertical surfaces and varies the illumination of sloping surfaces, in accordance with their inclination from the vertical. Shading from vertical illumination produces the logical progression "the steeper the darker". Oblique lighting produces more illumination on the sides of the surface facing the light sources, conventionally from the Northwest on maps, than on sides facing away. Level areas are shaded with an intermediate grey, steep slopes facing the source are shaded lighter and may be left white, steep slopes facing away from the source are shaded darker than the intermediate grey.

The intrinsic sources of ambiguity or confusion associated with hill shading methods were described by Yoeli[643], who was concerned with the merits of shading according to vertical, oblique, or combined illumination. He noted that a clear and natural appearance, most closely resembling reality, was associated with the unfamiliar perspective derived from the conventional Northwest lighting source. In a subsequent paper, he developed the theme of using the colour of the map to convey the colour of the earth's surface pictorially, and suggested how such a convention might be integrated with hill shading (Yoeli[644]).

True oblique shading conveys additional information about the slope and form of relief by distinguishing between slopes facing the light source and slopes facing away. However, by shading level areas it tends to make acceptable contrasts for overprinting more difficult to achieve. DeLucia[645] tested the effects of hill shading on the legibility of other non-relief map symbols and found that the inclusion of hill shading increased the time taken to locate and count overprinted symbols. Contrasts are an important factor in map legibility and wherever possible they should be maximised by minimising the use of area colours such as shading, and, where area colours are essential, by making them as light as possible.

Vertical illumination was preferred by Miller and Summerson[342] for aviation purposes because whereas oblique shading was "impressionistic", vertical shading or "slope zones" give a continuous gradation of tints directly related to the degree of slope. They also argued that the effect of oblique shading was dependent on the orientation of the map whereas slope-zone maps were omnidirectional. Wright and Pauley[349] pointed out that for Army low level purposes, oblique shading was highly conducive to disorientation and a possible hazard to flight due to a reversal of relief perception (ridges perceived as valleys) that tends to occur when the map is viewed at orientations other than north-up. The addition of layer tinting reduces the likelihood of reversals of shading perspective. Several slope-zone maps were produced by Miller and Summerson[342] with four slope-zone categories readily distinguished by the eye; eight distinctions were regarded by the authors as approaching the maximum that could be reliably discriminated and identified. Angwin[66] argued that a benefit of slope-zone patterns was their persistence over a wide range of map scales in a way which facilitated recognition of patterns despite large changes of scale.

The frequently voiced criticism of oblique illumination that the pattern of "shadows" rarely matches reality may be relevant to flight at high altitudes where the pattern is not perceptible. At low altitudes, two dimensional pattern matching is not possible because of the oblique perspective view of the terrain and matching is more likely to be based on the perceived shape and form in three dimensions, which is independent of the direction of illumination.

Keates[120] pointed out that vertical illumination has the disadvantage that very steep slopes cannot be represented effectively by shading because they do not occupy sufficient area on the map to be distinguished by the observer. There is also a lack of continuity between isolated features separated by unshaded areas. According to Keates[120] the more desirable system used in practice, combined illumination, incorporates the desirable features of both techniques. Level areas are left unshaded, and all sloping areas are shaded with darker shading on slopes facing away from the oblique source and lighter shading on slopes facing towards the source.

Hill shading is often shown in grey. This enables it to be distinguished from layer tints usually coloured buff or brown, and allows the shading to be discriminated as a separate though related image. Some authors have argued that hill shading should be better integrated with other relief codings. Tanaka[646] proposed a method of illuminating contours by oblique lighting to give an impression of shading. The result is highly effective but it is difficult to achieve graphically. For an example see Robinson and Sale[95] p.183. The point raised by Harris[157] on the influence of the colour of shading was followed by Carmichael[647], who concluded that the use of shaded layers with contours gave a better impression of relief when the shading was in the same colour as the corresponding layer. Whereas Carmichael's approach was to flout

convention by introducing innovative colour usage in a restrained way, Wilson[648] claimed that terrain on charts could be shown more effectively by changing the gradient tints and by using black shading. Curran[649] preferred pencil shading for relief portrayal.

In practice, most topographical aviation maps use grey oblique shading based on a flexible North-West lighting principle, to enable some shading of North-West orientated features. Level areas are unshaded to maintain contrasts for other cultural, natural and artificial information. The transition in shading from shallow to steep slopes should be gradual. The density of shading should be determined by the need to maintain discriminability of spot elevations, contours and layer tints when they are used. Dense hill shading tends to dominate the map image giving a highly exaggerated impression of terrain coarseness which may lead to undesirable, false expectations of the terrain shape.

Hydrography

Hydrographic features include the sea, coastline, estuaries, rivers, streams, canals, lakes, reservoirs, marsh and swamp, that is all features, both natural and man-made of which water is a constituent part. The portrayal of hydrography on aviation maps is superseded in importance only by relief and aeronautical information (McGrath[339]). Its high importance is due to the fact that hydrographic features are often the only permanent interior geographical features on the map and because of their visual prominence when viewed from the air. The size and contrast of major hydrographic features (coastlines, rivers, lakes) make them highly visible from the air, and their complexity of shape and pattern allows them to be identified accurately as visual checkpoints. McGrath and Borden[121] found that water bodies and watercourses were rated by aircrew as the most useful and dependable classes of features for checkpoints at low altitudes. At high altitudes, only paved roads and railroads were judged to have greater importance. Whereas at low altitudes watercourses and lakes are often obscured by relief and vegetation, McGrath and Borden[121] suggested that the greater importance of hydrography at low altitudes may stem from the pilot's preference for natural features rather than cultural features as dependable checkpoints. Water features also provide valuable information on the slope and shape of relief.

Barnard et al.[129], Bishop et al.[126], and Wright and Pauley[349] all endorsed the importance of hydrographic features, particularly small streams, for navigation at low altitudes in helicopters. At night, coastlines, bodies of water and large rivers, in that order, were regarded as the most important topographical features for fixing positions en route at low altitudes, in fixed and rotary wing operations, largely because water surfaces either reflect light or appear as dark areas depending on the ambient illumination (Taylor[348]). Coastlines and large inland bodies of water are important checkpoints for radar navigation because of the lack of radar reflectivity and should be prominent on maps for radar-map matching (Barratt et al.[345]).

On topographical maps hydrography is normally represented in blue. This convention is probably too entrenched to be changed, even if evidence existed (which it does not) that a change would be beneficial. Depending on the scale of representation and the specific feature, hydrology may be shown by point, linear or area symbols. River names are also shown in blue. For point and line symbols, a saturated (high chroma) dark blue is required that contrasts highly with white, and with layer tints usually buffs or browns. Large areas of water (estuaries, seas and lakes) may act as a background for other overprinted information and their contrast requirements necessitate the use of light, desaturated or screen blue tints. This introduces at least one visual discontinuity somewhere between the headwaters of a river and the ocean it ultimately flows into. Casing of large rivers and bodies of water may be necessary to emphasise their shape when they are coloured in light blue. Casing should be in a saturated dark blue, to contrast with the blue infill.

Man-made waterways are normally distinguished from natural hydrography by their comparative regularity. Shape coding of lines (peckings, interruptions) may be added to distinguish seasonal rivers and the limits of tidal variations (broken lines) from permanent water courses (continuous lines), and to distinguish between types of canal (navigable, non-navigable, disused) and types of aquaduct (under ground, over ground). Repeated point and line symbols coded in blue should be used to distinguish between swamps and marshes. Swamplands may present problems of depiction on aviation maps, where the primary concern is whether they look like land or water from the air. To use too much blue in depicting may lead to uncertainty about where a coastline actually is, or how a delta estuary is likely to appear from the air. A further problem occurs with impermanent ice, which, being transitory, cannot be mapped, but a convention is needed to show its impermanence. Maps do not normally portray a direct relationship between water and permanent ice, to the extent of showing them as the same substance, but maps follow the more pictorial conventions of depicting ice usually as white, in so far as this is compatible with other conventions.

Coding of ocean depths may be necessary on maps for maritime operations. Bathymetric contours are normally shown in dark blue to contrast with screened or desaturated sea blue; bathymetric tints, if shown, should be coded in screenings of blue on the principle "the darker the deeper". Light blues for sea on some map series may fail to give adequate contrasts for coastlines when land mass or first layer interval is white. This can be overcome by vignetting of coastal waters or by colour coding the land mass, for example with a first layer interval in green.

The main design problems with hydrography on aviation maps concern generalisation and classification. In regions with numerous small lakes the cartographer must decide what lakes to exclude on the basis of size and to judge the selection to represent correctly the essential characteristic of the region, e.g. numerous small lakes. Small isolated lakes may be visually significant from the air but the scale of the map may prevent them being accurately represented and they

may need to be exaggerated in size or omitted altogether. McGrath and Borden[121] showed that the selection rate for bodies of water on three major aeronautical charts was far lower than their visual utility would warrant.

In representing coastlines and the shape of large lakes, the visual utility of these features means that the cartographer should make a special effort to show significant configurations even if the scale must be exaggerated.

McGrath[339] argued that most aeronautical charts portray far more streams than can be used in high speed low altitude flight. Streams may be detectable, but their frequency and indistinctiveness may make them impossible to identify positively as position checkpoints.

Vegetation

A complex symbology has evolved on maps to depict vegetation (McGrath[650]; Keates[120]). Various small repeated symbols, usually colour coded in green, have been used to distinguish between different types of vegetation, e.g. bush, dense bush, orchards, deciduous or coniferous wood, and meadow. On aviation maps only relatively permanent vegetation can be of practical use for navigation and even woodland must be treated more circumspectly than other natural features, particularly in regions where woodland is a crop. Even the largest and most distinctively shaped woods can be cut down between revisions of a map sheet.

The main requirements for vegetation on aviation maps are for orientation purposes – indicating general land cover, distinctive patterns and landmark features, possible obscuration of other checkpoint features, e.g. rivers in jungle; and for tactical purposes – indicating ground cover that might be used to avoid detection during helicopter operations, and showing likely barriers and funnels for movement of ground forces. Tall trees on hills might be considered to be a safety hazard to low flying aircraft.

The importance of vegetation for visual referencing varies in different parts of the world. McGrath and Borden[121] did not include vegetation in their study of visual checkpoints because in the Sierra Nevada foothills of Central California, the area of their study, vegetation was sparse and indistinctive when viewed from the air. Yet McGrath[339] noted that in other areas of the world, such as Europe, distinctive patterns of stable woods are useful aids to low-level navigation. However extensive, dense afforestation, such as the jungles of SE Asia, may be as unhelpful for visual referencing as thin, sparse scrubland. It is the clarity of the edges, boundaries and shapes of woodland rather than their interiors that carries accurate locational information.

To meet the needs of air users, vignetted vegetation symbology has been developed for use on the JOG and TPC Series. This has the advantage of depicting small woods in a solid green tint and emphasising only the boundaries and clearings of large woods, leaving their interiors clear apart from small repeated tree symbols. The alternative to vignetting, more common on land series and older air series, is to use a solid green tint, but in mountainous areas this reduces contrasts and tends to "flatten" the three-dimensional impression of hill shading. Contrasts for contours and layer tints may also be reduced below the minimum required for discrimination under operational conditions. Overprinting green also changes the colour of layer tints and makes comparisons difficult between the wooded and clear areas. A light green tint may be used to minimise the effects on relief contrasts, but this tends to make the wood boundaries less perceptible and they may have to be emphasised by casing.

Taylor[100] compared cultivation and forest symbols on a standard and experimental JOG Series sheet measuring times and errors on a symbol identification task. Cultivation on both maps was shown by a regular pattern of small green dots. Making the dots larger and increasing their separation significantly improved ($p < 0.05$) their legibility on the experimental map under degraded (projected image) viewing conditions. Forest on both maps was shown by vignetting with repeated tree symbols. Increasing the size and spacing of the repeated tree symbols on the experimental map reduced, though not significantly, the numbers of correct identifications of forests under non-optimum viewing conditions. Forest symbols on both maps were assessed at below average legibility judged by the percentage of correct identifications. It was concluded that poor edge contrasts accounted for the poor performance with both types of forest symbols, and that all vegetation symbols using repeated symbols were only marginally legible.

Taylor[159] reported an experimental comparison of five types of wood symbols printed on a TPC extract sheet:–

(1) Uncased narrow green vignette, fading to a cleared interior with repeated tree symbols.
(2) Broad green vignette, fading to a cleared interior with repeated tree symbols and green casing.
(3) Light green solid tint with green casing.
(4) Broad green vignette fading to light green interior with green casing.
(5) Dark green solid tint with green casing.

Forty subjects were tested on their ability to recognise wood shapes (wood recognition) and base map detail (base recognition) with all five types of wood symbology compared with performance on the base map with no woods pattern and on the woods pattern alone in a solid green tint with no base map (experimental controls). The results showed a performance decrement on both tasks with all the symbol types compared with the experimental controls. Response times for woods recognition increased by an average of 300% compared with 135% for base recognition. The pattern of results for individual symbols broadly agreed with what would be expected on the grounds of ink saturation, brightness and colour contrast. The solid dark green tint was best for woods recognition, the light green tint was worst, closely

/ 90

followed by the narrow green vignette. On base recognition, the light green solid produced the best performance and the narrow vignette was worst. It was concluded that the relatively poor performance of the narrow vignette symbol was partly determined by the increased clutter caused by the effective doubling of edge contrasts with this kind of symbol, and partly by poor figure-ground segregation.

In complex patterns, such as woods on maps, good figure-ground organisation is important. With vignetted symbols, it is difficult to distinguish the areas that lie within the woods from the areas outside. The woods interior is only defined by repeated tree symbols. These symbols are indistinctive and lack the perceptual qualities needed to integrate the wood shapes into a coherent, stable 'whole'. Perimeter vignetting may work well with relatively simple, regular shapes such as controlled airspace, but the technique seems to possess too much ambiguity for complex wood shapes.

Vignetted symbols therefore seem to have serious disadvantages compared with solids for portraying wood patterns, and their advantages in terms of improved legibility of other information have yet to be demonstrated empirically. A sensible compromise between the requirements for woods and relief representation would seem to be to omit extensive woods on high ground, emphasising the more important relief information – as allowed for in the TPC specification – and to portray individual woods in solid saturated, light green tints elsewhere, but only where they are comparatively small and isolated (Wright and Pauley[349]; Taylor[159]). Numerous individual woods in a small area are likely to be confused. Casing of light green solid tints may improve the perception of edge boundaries, but introduce undesirable clutter. The value of casing woods symbols needs to be checked empirically. When unsymbolised woods cover large land areas notes such as "Generally Forested area" should be overprinted on the topographical base for general orientation purposes and to avoid confusion.

The high degree of selectivity required for vegetation representation on aviation maps means that particular attention must be given to classification, delineation and generalisation. Edge boundaries are often transitional, difficult to survey and difficult to recognise from the air. Dense woods, with well-defined boundaries and distinctive shapes (e.g. the 'T' wood) are more likely to be useful in flight. In generalising vegetation, the cartographer should seek to emphasise the dintinctive shape characteristics, even at the expense of scaling accuracy, so that memorisation, recognition and identification are facilitated.

9b MAN-MADE FEATURES

The significance of man-made features on aviation maps need not bear a close relationship to their importance for map users on the ground. However, the selection and representation on maps of man-made features is strongly influenced by conventions which reflect their significance or utility for the map user on the ground who encounters them directly at close quarters. From the air, features may merely be glimpsed, particularly in high speed low level flight, or seen through haze from a distance. Vertical features can appear prominent when viewed from the ground, but may be hard to see at all from high altitudes. In low altitude flight, the importance of vertical features depends on their visibility rather than on their absolute height, which are not always related (e.g. tall buildings in cities) and on the extent to which they are a physical obstacle and a safety hazard (e.g. pylons). Viewed from the air, the pattern and sequencing of man-made features are often more important for visual navigation purposes than their functional classification (e.g. classes of roads). Thus, the generalisation and selection criteria tend to be more important determinants of their visual utility than coding differences between classes of features. Some functional distinctions may be needed for tactical decision making and target designation but these tasks are normally carried out on different large scale maps from those used for visual navigation purposes.

Differences between the requirements for man-made features on maps for air and ground purposes mean that aviation maps produced by overprinting air information on a standard topographical base are unlikely to be totally acceptable to aircrew. The much criticised air version of the Series 1501 Joint Operation Graphic is a case in point (Lakin[633,340]). Main roads were judged by aircrew to have been over-emphasised in comparison with important natural features of relief, water and woods (Lakin[340]). Yet, clear portrayal of main roads was required on the ground version for tactical, logistic and route planning purposes.

The simple point, that the cartographer normally maps the ground and therefore the ground is his main frame of reference, has many implications for the design and usage of aviation maps. What is mapped on the ground is not necessarily what is most visible, even from the ground, but what is most important on the ground. Some categories of information are visible from the air and invisible on the ground, e.g. patterns and shapes of plan features – hence the recent interest in the location and plans of prehistoric settlements as revealed from the air. Some items of information, visible from the air, are unimportant to all but a few map users on the ground, and are therefore not normally mapped – field patterns are an example. Some items of information may or may not be removed from maps when they are no longer there, and it may be difficult to judge how visible from the air their vestiges are likely to be – disused or abandoned railways are an example. Some items of information of great interest to map users on the ground may not be very prominent from the air and may be of limited value even when they are – for example, road networks in towns.

A further complication is added by the presence of various forms of collateral material on a display in the cockpit, derived from sensors such as infra-red or radar. These may, as a characteristic of the sensor, include or exclude certain information categories and assign them relative visual prominences on the display, which bear no logical or systematic

relationships to what is directly visible on the ground from the air, or to what seems important enough on the ground to appear on a map. Forward looking radar imagery, with its association between the vertical extent of a feature and its visual prominence on the display, adopts a criterion which tends to be alien to maps which must somehow attempt to portray verticality on a flat horizontal surface. Infra-red sensors, which emphasise shadows and introduce variability of visual prominence on the display associated with such factors as weather and time of day, lead to the problem of pattern discernment which is independent of relative prominence, where many of the pattern elements, such as small walls and ditches, are so unimportant on the ground that they are not mapped at any of the scales which are usable for aviation purposes. One application of human factors principles to categories of cartographic information is therefore to emphasise that for some roles in aviation certain of the most prominent categories of information are not mapped at all. This applies most forcibly to man-made features. Some of the features which are mapped may be assigned a visual prominence which their operational utility would not strictly warrant, but which is partly to compensate for the absence of those information categories which are not mapped at all.

The visibility from the air of information on the ground, and its relationship to aviation maps was discussed as a problem by Wulfeck et al.[101]. Approaches to the problem of how to apply human factors data to the practical solution of cartographic problems must rely not only on the human factors data but on the logical categorisation and sub-categorisation of symbology (Ratajski[498] and on the associational value of symbols in evoking at once the objects they represent (Koponen et al.[331]; Van der Weiden and Ormeling[501]). It is therefore misleading to treat the application of human factors principles to evolve cartographic information categories solely as a psychophysical process. However, certain factors should be borne in mind in relation to specific categories.

(1) Roads

The classification of the transport and communication structure based on the needs of the road user is not of much relevance to the user of aviation maps. Detailed classifications of roads, surfaces and tracks may assist tactical decision making, reconnaisance briefing and target planning. On 1:50,000 scale maps, they can assist orientation in low level helicopter operations (Wright and Pauley[349]; Barnard et al.[129]). Some of the design problems of roads representation to meet ground user needs have been addressed by Astley[651], and Morrison[652,514,653]. But these issues are only relevant to the requirements for visual referencing and orientation in high speed flight when they correspond to major differences in size, contrast and visibility from the air.

In low altitude high speed (LAHS) flight, McGrath and Borden[121] reported that paved roads were the most generally useful features for orientation judged by aircrew studying air to ground films. For use as checkpoints, however, individual paved roads were judged to be the third most dependable feature after water bodies and water courses. Trail patterns and dirt roads were rated as having the lowest visual utility of the eight classes of features tested. Estimates of their utility for visual referencing based on the appearance of the features on three maps (Sectional, USAF Pilotage Chart, ONC) showed no significant difference between cartographic utility and visual utility for paved roads, indicating that they had an appropriate cartographic emphasis. Dirt roads had higher cartographic utility than visual utility on the 1:500,000 Sectional Aeronautical Chart due to their inclusion in a broader, more emphasised category of secondary roads. The selection rate for paved roads on maps was found to be high, consistent with their high utility, but the choice of individual roads was generally poor and unrelated to their relative discriminability from the air. Ideally a 100% selection rate would be better than at random, but as this is impractical the authors recommended that all paved roads should be portrayed only when the scale and density of features allowed. A low selection rate for dirt roads was also consistent with their visual utility but again the selection was indiscriminate. In this case, the best strategy would be to portray no dirt roads in the absence of valid selection criteria, as there can be little point in showing only a few dirt roads if the few chosen are no more useful than those that are not.

The value of roads in flight is inversely related to their frequency of occurrence and it is in direct proportion to the traffic they normally carry. Their importance may also vary with the map task. Roads were rated the fifth most important feature for flight planning and third most important in flight by users of 1:250,000 scale Joint Operations Graphic (Lakin[340]). Despite their high importance, many aircrew considered that main roads had been over-emphasised. Showing all "minor roads" was favoured by 69% of aircrew although an earlier study (Lakin[633]) had expressed the view that too many minor roads cluttered the map. Murrell[131] also recommended that "minor roads" should be included on 1:250,000 mapping. A high proportion of aircrew chose to include them on a LAHS map but the importance ratings of minor roads were generally low. This was taken as indicating that whereas individual minor roads had to be unimportant, collectively (i.e. their pattern and structure) minor roads are of high importance. For night low level visual referencing, Taylor[348] found that aircrew rated motorways (Rank 5) as equal in importance to obstructions (lighted) for fixing positions. "Major roads" were ranked eighth and secondary/minor roads fifteenth.

Most sources comment on the importance of distinguishing and emphasising motorways and multiple carriageways on aviation maps because of their high visibility and discriminability from the air. Barnard et al.[129] reported that the blue coding of motorways on OS maps leads to confusions with hydrography during brief glimpses in flight, and suggested that coding of illuminated roads would be a useful distinction for peacetime, night flying. Bridges, Flyovers and Roundabouts are invariably highly distinctive from the air, particularly "clover-leaf" configurations on motorways, but they are often presumed and not explicitly depicted on small scale maps. A standardised pictorial symbology needs to be developed for each of these features.

On the coding of roads on maps, both Keates[120] and Wood[188] pointed to the possible confusion of linear features and boundary lines of area features. Clear coding distinctions are necessary by variations in shape, size and colour. Parallel lines, with and without various infills, are a common shape coding distinction for roads that has received some general acceptance on 1:50,000 and 1:250,000 scale maps. This has the disadvantage of increasing line clutter, so that on smaller scale maps, where the density of features tends to be greater, single line representations are usually preferred. Solid single lines are used on the TPC and ONC.

Variations in symbol width or weight are usually employed to code differences in road classification, principal or primary roads having the greatest width, secondary roads an intermediate width, and minor roads the narrowest width, in accordance with their visual utility. Motorways and dual carriageways are most effectively represented by a dual symbol. Some guidance on the saliency of different line widths can be obtained from Wright[181], who found that the perceived difference between line widths for solid lines increased with increases in the ratio of the difference in line width and the width of the wider line. In other words, a given difference in line widths is more perceptible for thin lines than for thick lines.

Whereas it seems plausible to argue that a unified colour coding of roads should facilitate the perception of the structure of the road network (Wood[188]), some series, notably the JOG, use a combination of width and colour coding to distinguish road classifications. Evidence presented by Taylor[100], on a symbol identification task, showed that with the JOG specification, subjects tended to confuse secondary roads (screened brown infill) with principal roads (solid infill) and minor roads (no infill), presumably because of discrimination and identification difficulties. A different coding, using the same colours for both principal and secondary roads, alternating red and white infill in different proportions proved more successful than the JOG specification. However, the symbol lacked continuity and tended to produce more visual clutter. The conventional minor road symbology – two parallel lines, 0.56 mm apart – achieved less than 60% correct identifications under degraded viewing conditions (projected image) whereas the solid infill symbol (0.81 mm line space) for principal roads was highly legible under all the conditions tested.

The conventional colour for coding roads on land maps is red or near-red (orange, brown). Unlike many other colour coding conventions, red does not have a particularly high associational value with roads and this convention should not be regarded as sacrosanct. Red was used on early aviation maps for road coding because it disappeared against a light background under red cockpit lighting and roads were unimportant during night operations. Current specifications for JOG, TPC and ONC Series code roads in dark brown colours that maintain their contrasts under red light. This is probably due to the difference between peacetime and wartime requirements as much as to any real change in the utility of roads at night. In any event, a cardinal rule in the colour coding of linear features such as roads is that the colours must have high contrasts to maintain adequate legibility. Wood[188] has noted that when lines are narrow there is a tendency for all colours, with the exception of yellow and bright red, to be seen as black, an effect that is probably due to small-field tritanopia. Disregarding red light legibility, a saturated (high chroma) bright red infill, with black casing (parallel lines) may yet be the most suitable colour code for roads, confirming, once again, the fundamental validity of most cartographic conventions.

McGrath[339] regarded the correlation of roads on the map with roads on the ground as one of the most difficult map interpretation problems in low altitude flight. Variations in the selection rate in different regions partly account for this; also the basis for selection is more often the continuity or uninterrupted length and the importance of the terminals. Pilots should appreciate that, except in open country where most roads will be shown, they will see more roads on the ground than are represented on the map. In general, the likelihood of an individual road being portrayed reduces as the number of roads in the area increases. Finally, road classifications can be misleading and do not necessarily correspond to their visual appearance. In many cases it may be difficult to identify roads on any other criterion than planned time of arrival.

(2) Railways

Railways are generally regarded by aircrew as important features on topographical maps. Apart from their tactical significance in representing the transportation and communication structure, they are comparatively easy to detect and identify from the air at both high and low altitudes, partly because of their width and contrast and their comparative infrequency, but largely because of their tendency to follow straight lines. Their lack of sinuosity among line features, comparable only with motorways, makes them excellent features for along-track following at low altitudes. Combined with point features such as stations, and crossed by other line features, they make good positional checkpoints. Like all linear features they are of less value when they cross the aircraft track obliquely, but their comparative infrequency makes them relatively easy to identify across track compared with roads.

For helicopter operations, Barnard et al.[129] found that aircrew rated used railways as extremely useful and disused railways as very useful for day nap-of-the-earth and low level transit flying. At night used railways were moderately useful if lighted by traffic or series of signal lights, or if moonlight reflected from the rails. The value of disused railways depended on their age and on what traces remained. Cuttings and embankments can remain visible for a long time on disused railways but whereas these were useful during the day they were virtually useless at night. Helicopter aircrew felt that on 1:50,000 scale maps railways were very well represented and whereas railway stations tended to be over emphasised, cuttings and embankments could be depicted better and tended to be removed from maps when in disuse far sooner than their visual utility warranted. This is largely because 1:50,000 scale maps are designed primarily

to meet the needs of ground users. Disused railways are included in an electric blue overprint of air information for air-crew users of the Ordnance Survey Northern Ireland one inch series.

Lakin[340] found that aircrew users of 1:250,000 scale maps ranked railways third in importance as topographical features for flight planning and second in importance in flight following water features. Although they were generally satisfied with the representation of railways on the Series 1501 JOG, they considered level crossings and railway stations should also be included. Murrell[131] found no support among aircrew for the inclusion of disused railways on 1:250,000 scale maps for LAHS flight, but used railways were judged highly important. McGrath and Borden[121] found that the visual utility of railways judged from low altitude films was high, but pilots tended to over estimate their usefulness from their appearance on maps. It seemed that their bold rendering on maps made them appear very prominent and more distinctive than they actually appear on the ground. Also aircrew placed high value on railways, not because they were particularly easy to detect, but because once detected, they were easy to identify. Pilots were unable to discriminate differences in the utility of railways based on their appearance on the map, except between single and multiple tracks, probably because of their otherwise uniform symbology. Examination of the selection rates for railways on Sectional, PC and ONC Charts showed that the rates were much higher than their real visual utility would warrant. The general rule seemed to be to portray all railways irrespective of differences in utility probably because they are easy to identify, and because the relatively small numbers of railways, unlike roads, justifies a high selection rate.

For night low altitude navigation, Taylor[348] reported that railways were ranked tenth out of fifteen features by aircrew, judging their importance for fixing positions. Their importance varied with the type of operation:– helicopter aircrew ranked railways ninth, tactical transport aircrew ranked them eleventh, jet aircrew ranked them twelfth. Like most linear features it seems likely that railways become less important as checkpoints as the aircraft speed increases.

The practice of using black lines with crossties for coding railways is one of the nearest approaches to a universal convention on maps. ICAO recommend the conventional railway symbology for aeronautical charts: single ties for single track; double ties (or two parallel lines with a single tie) for multiple tracks; broken line with ties for a railway under construction (Anon[654]). The JOG, TPC and ONC all use a continuous black line with single and double ties for single and multiple tracks, and a broken line for 'non-operating' (disused) tracks. Koponen et al.[331], in their study of the associational value of map symbols, found that whilst pictorial symbols were usually better than geometric forms, the geometric symbols for railways were easily interpreted partly because they were highly conventionalised and partly because the bends and curves of the symbol corresponded to recognisable patterns on the ground. They rated the ICAO standard symbols used on the 1:1,000,000 world aeronautical chart as good. Lakin[633] found that 90% of aircrew respondents to a questionnaire evaluation of the JOG considered the classification of railways on the map to be adequate. Wright and Pauley[349] also favoured the conventional railway symbology for helicopter tactical maps, contrary to Bishop et al.[126] who called for a more pictorial symbol.

Empirical testing of the legibility of the single track railway symbol on the JOG by Taylor[100] gave virtually 100% correct performance on an identification task under normal and degraded (projected image) viewing conditions. Similar performance was obtained for a symbol for railway stations using a black circle with red infill. Under degraded viewing conditions the size and spacing of tie bars are probably the critical features in the identification of conventional railway symbols. It would seem that the sizes and spacing of tie bars used on the JOG (0.20 bar line width, 1.52 mn length, 3.81 mn space) are probably adequate for most applications.

Black coding maximises the brightness contrast for railway symbols. Consequently any change in railway colour coding will reduce contrasts and may cause legibility difficulties with conventional size dimensions. The size dimensions of tie bars would need to be increased to maintain the same level of legibility under lower contrast conditions. On many charts, grid lines are also coded in black and are a potential source of confusion with railways particularly as they are often pecked to facilitate interpolation. The possibility of serious confusion is reduced by the regularity and alignment of grids. Pecking the grid lines on one side of the line distinguishes them further from railway symbols. Whereas, McGrath and Borden[121] have produced evidence that railways may be over emphasised on maps, their relative infrequency means that this is not a major problem. In face of the highly conventionalised use of black coding, one must conclude that at present there is insufficient evidence to justify a change of colour.

On the interpretation of railway symbols on maps, McGrath[339] recommends the following maxim: "I must not see it, but if I do, I will very likely be able to identify it on the chart". He points out that railways are generally easier to detect from the air in hilly or mountainous terrain than in flat populated areas. In mountains, the track is normally characterised by numerous cuts, fills, trestles and tunnels, all features that enhance detectability. Tunnels are shown on most maps by two curved lines concave to the visible track and joined by a broken line. This has a desirable pictorial quality without being unnecessarily elaborate. Cuttings are not shown on small scale maps because of limitation on space and accuracy of representation. McGrath[339] also points out that railway yards make excellent radar checkpoints. On the TPC they are generally shown if they exceed 2,000 feet in length and five tracks in width.

(3) Communities

From the air, the characteristics of communities and populated places that are most likely to be distinguishable are the general size and shape of the built-up area, and the pattern of roads, railroads, rivers and distinctive structures within. Like vegetation, the visual boundaries of built-up areas are often ill-defined, rapidly changing or not known. They may

change at night when illuminated by street and domestic lighting. Depending on the scale of representation, it may be impossible to portray the distinctive shape characteristics without sacrificing accuracy.

Dornbach[127] pointed out that on aviation maps the outline of towns was of prime importance and that population size or density, normally used to classify the importance of towns, was of secondary importance. Most sources suggest that built-up areas are rated medium to high on relative importance for visual navigation compared with other features. For helicopter operations, Barnard et al.[129] found that towns and villages were rated very useful for day transit and nap-of-the-earth flying. At night towns became extremely useful when illuminated and were ranked first of forty-one features, but villages became less useful. For aircrew users of 1:250,000 scale mapping, Lakin[340] found that city and town shapes were ranked ninth in importance for flight planning and in-flight. Murrell[131] placed towns about fourth in priority for low altitude high speed mapping and in Taylor[348] they were ranked fourth by helicopter, transport and jet aircrew for fixing positions during night low level navigation.

McGrath and Borden[121] obtained similar estimates of the relative visual utility of communities judged from air to ground films of low altitude flight. Aircrew consistently over-rated the importance of communities according to their appearance on the Sectional, Pilotage Chart and Operational Navigational Chart. The authors concluded that this discrepancy arose because the manner of depiction on the maps used clearly defined symbols and place names which suggested prominence and uniqueness for features that were frequently indistinct dispersions of buildings on the ground. Selection rates for communities were generally low compared with their visual utility but those selected were generally well chosen being based to a great degree on area size.

The over-emphasis of built-up areas is a common feature of most maps particularly at 1:250,000 and it is difficult to avoid without reducing edge contrasts for towns to levels that are unacceptable for operational conditions. Even with comparatively high contrast grey infills, aircrew commonly colour in town shapes with black ink prior to night flying missions (Barnard et al.[129]; Taylor[348]).

A variety of symbols is used on aviation maps to represent communities and populated places. The ICAO standard lists four different symbols:

(1) City or large town – black outline with yellow or black stipple infill
(2) Town – Black circle
(3) Village – Smaller black circle
(4) Buildings – Small solid black squares and rectangles.

Three categories are shown on the ONC: a black outline with yellow infill, and two black squares, the larger with yellow infill for towns of unknown outline. The TPC also distinguishes three categories, using a purple infill for the first two (outline and square), followed by an open small black circle for towns of third importance. On the 1:250,000 scale, JOG representation of communities is more detailed. Five categories differentiated by population size are symbolised by different type sizes for place names. Outlines with dark brown infill are shown when the shortest dimension exceeds 0.15 inches; otherwise individual buildings (small black squares) are used to represent small and scattered communities. The principal on the JOG was to show all populated places and buildings wherever possible, and in dense areas to show only a selection that retained the balance with other features. However on some sheets of the JOG Series the portrayal of individual building in clusters creates a cluttered and untidy appearance. For example, the use of dots on Malaysian sheets of the Joint Operations Graphic can become so dense that each single dot becomes valueless for operational purposes, and the only information conveyed is the presence of numerous settlements. These may range, however, from substantial groups of buildings to huts in dense woodland, and it is difficult to predict what will be seen from the air, or even whether it is sensible to choose such settlements as fixpoints. Some prove to be highly visible and useful; others may be impossible to see.

Hopkin[70] argued that for air purposes numerous individual buildings were of doubtful operational value and were more likely to be detrimental to map reading because of clutter. Similar advice was given by Taylor[222] following a comparative study of the suitability of the JOG and other 1:250,000 scale maps for LAHS flight. Recent revisions of the JOG specification to bring it into line with critical user requirements have included deletion of the symbol for individual buildings so that only communities that are large enough to meet the requirements for outline symbols are shown.

Comparisons of the major aviation map specifications show little evidence of any consensus on the optimum town infill. Screened brown, screened purple and solid yellow are used on the JOG, TPC and ONC Series respectively although they all have broadly similar colour coding in all other respects. Grey (black stipple) is used on the RAF Low Flying Chart, having replaced yellow on earlier editions, because of edge contrast problems, and grey could be argued to have the highest association value. Like the JOG brown, grey gives good edge contrast, facilitating shape recognition, but it lacks the attention getting properties and high contrast for overprinted line detail that is obtained from yellow. Purple and brown are also favoured because they retain their contrasts under red cockpit lighting, a legibility constraint that if only for consistency should apply to the ONC infill. Yellow loses contrast and virtually disappears on the ONC under red lighting.

Taylor[100] compared identification performance on outline town symbols on the JOG (maroon/warm brown effect) with the same symbols with a solid grey infill. Almost 100% correct identification accuracy was obtained with the grey infill for normal and projected image viewing. The JOG infill produced more errors under both viewing conditions, the difference reaching statistical significance ($p < 0.05$) for projected viewing.

Red and yellow were suggested by Keates[120] to be common town infills on general purpose topographical maps because of their high contrasts for line detail and because of their distinctiveness from the colours of natural features. Keates added that large areas of red tend to dominate the map image and the colour needs to be desaturated in large built-up areas in order to maintain good visual balance. He also suggested that the same infill colour should be used on both outline and geometric (circular or square) symbols for towns to maintain continuity of coding. It is unlikely that red will be an entirely suitable town infill for aviation maps, partly because of red light legibility objections, and partly because red coding has greater utility as a warning device for coding obstructions and restricted airspace, features that tend to be associated with built-up areas.

The variable use of circles and squares to indicate secondary and tertiary levels of classification is undesirable and potentially confusing. Users of the ONC and TPC could be forgiven for assuming that the square geometric symbols used for communities with unknown outlines, indicate towns with square outlines. Circular symbols, as recommended by ICAO, are less likely to be misinterpreted in this way. Keates[120] suggested a logical set of circular symbols, varying in infill and gradually increasing in size to an outline symbol. Psychophysical data on perceptible differences in the size of circles may help to guide their design to achieve an even, discriminable progression (Cuff[600]).

Representation of the internal structure of roads, railways and rivers may assist in the identification of built-up areas when the outline shape is poorly defined. On 1:250,000 scale maps this can be readily achieved for most medium to large scale communities. On smaller scale maps, there is often insufficient space for the pattern to be resolved. Detailed representation of the communication structure on large scale maps tends to break up the outline shape and should be restricted to the primary routes and major rivers. On the JOG, the same colour is used for secondary routes and town infill. Secondary routes entering towns are cleared of colour and portrayed by white lines. Primary routes are coded in the solid of the screened infill colour and printed continuously through built-up areas. The net result is to increase the emphasis on the road network and reduce the prominence of town shapes. From the air users' point-of-view, this change is probably undesirable. This de-emphasis of town shapes could have been minimised by coding town infill and roads in different colours.

McGrath[655] cautioned aircrew against relying solely on the shape of built-up areas for identification because of the problems of representing suburbs on maps. The pilot should try to use some unique element or associated features for positive identification such as a stadium, airfield, cemetery or marshalling yard. The most difficult problem, he argued, concerns the interpretation of standardised symbols for populated places which on maps such as the TPC represent such a wide range of communities which may or may not be visually recognisable from the air. Generally, they should not be relied upon for checkpoint features except in association with other features that allow positive identification to be made.

(4) Isolated Structures

Large isolated buildings and structures such as sports stadia, racecourses, open air cinemas, large factories, power stations, chimneys, lighthouses, oil wells, bridges, viaducts, dams, quarries and mines may constitute distinctive features from the air, useful for fixing positions during both radar and visual navigation. At low altitudes major structures with vertical developments such as tall buildings, radio masts and power transmission lines, are also hazards to flight safety. These will be discussed under air information in the following section.

Barnard et al.[129] found a strong requirement for tall chimneys, power stations, high rise buildings, and church steeples in flat terrain and disused quarries on 1:50,000 tactical maps for helicopter operations. However, bridges were rated by helicopter aircrew to be less well shown than their usefulness warranted. For low altitude high speed flight, Murrell[131] found that the value of individual structures depended on their precise location. Stately homes were rarely built in exposed positions whereas smaller windmills were highly distinctive because they are normally built on high ground. Compared with other topographical features the relative importance of incongruous features may not be as high as one is tempted to assume; Lakin[340] found that aircrew rated landmark features twelfth in importance for flight planning and eleventh in flight. At night, landmarks were ranked thirteenth in importance for fixing positions during low altitude navigation (Taylor[348]).

The value of isolated structures for fixing positions lies in their distinctiveness from other features and from each other. Maps such as the JOG and TPC use standardised pictorial symbols for landmark features which while possessing desirable clarity and simplicity of form, tend to blur the important individuality. Ideally, each feature should be portrayed in a manner that exaggerates its distinctive characteristics, (the number of chimneys, bridge spans etc). In practice the cartographer is often forced to use standardised symbols because of limitations on scale and survey data. McGrath and Borden[121] found that the clarity of standardised symbology for structures had the further disadvantage of causing aircrew to over rate their utility judged from maps compared with their visual utility seen from the air at low altitudes. Excavations, on the other hand, shown by crossed picks under-emphasised their real visual utility.

Advising aircrew on map interpretation problems at low altitudes, McGrath[655] pointed out that bridges and viaducts were only depicted on the TPC when they exceeded 800 feet in length. Below this length, their presence should be inferred. Similar limits apply to other maps. On major structures generally, their selection for portrayal on the TPC depended on whether or not other significant features were in the area. The symbol for a large factory, for instance, would not be shown in built-up areas but would tend to appear in isolated regions. Standardised symbols cover a wide range of features and the pilot should be wary of searching for a good pictorial likeness on the ground. In some areas, more than one pictorial symbol may be shown in close proximity (e.g. oil wells). This is intended to indicate the general pattern of features rather than their individual locations. Consequently, the pilot should not attempt to carry out a precise visual fix on any one symbol in a group of similar symbols. Finally, McGrath[655] cautioned pilots that some structures were hazards to flight but not necessarily visually significant from the air (e.g. power transmission lines).

Some broad aspects of the design of pictorial symbols were covered by Koponen et al.[29] and Chainova et al.[555]. Taylor[100] compared various landmark symbols on an identification task and concluded that pictorial symbols were preferable to feature names provided that the symbols were bold and simple in form with easily recognised meanings. Water towers and large buildings (factories, power stations, lighthouses) were portrayed on an experimental 1:250,000 JOG map using pictorial symbology, replacing labels denoting the names of features on the original JOG. Whereas the bold TPC silhouettes used for large buildings were highly successful, producing statistically significant improvements in identification performance, the fine line drawing for water towers was substantially less legible than the original label. Abstract shapes were acceptable when they were conventional symbols, such as for churches, but they must also be bold and simple if they are not to beconfused with similar symbols such as for mosques and small individual buildings. Taylor[100] listed the following primary rules for designing pictorial map symbols:

(a) Contrasts should be maximal.
(b) Shape should be distinctive in general outline, not in fine detail.
(c) Minimum size should be determined by the smallest component that has to be recognised.
(d) The symbol should have high association value, and compatibility between coding and meanings.

Many of the symbols proposed by ICAO as standards for isolated structures on aviation maps (Anon[654]) fall short on more than one of these criteria.

9c AERONAUTICAL INFORMATION

Aeronautical information refers to data on radio facilities, airfields, air traffic control, airspace regulations and obstructions provided on maps to aid air navigation. Instrument navigation or IFR charts, terminal area charts, instrument approach charts etc are predominantly concerned with aeronautical information. Maps for visual navigation contain both topographical and aeronautical information, partly to facilitate the transition from VFR to IFR procedures and partly because some aeronautical information is always necessary for flight planning and flight safety, e.g. airfields, obstructions, danger areas.

Whereas classification, selection and generalisation are major issues in the representation of topographical information, symbolisation and coding are more important in depicting aeronautical information. Selection tends to be on an all-or-nothing basis depending on the map function. Only obstructions and power transmission lines occur with sufficient frequency to create a potential selection problem and on small scale maps the selection can be based on relatively simple yet valid height criteria (e.g. over 200 ft AGL). Generalisation is necessary in the representation of power transmission lines and airfield plans at large scales. All other classes of aeronautical information are either point features (e.g. radio facilities) or simple regular shapes (e.g. airways) not requiring generalisation. Most sub-classifications of air information (e.g. types of aerodromes and radio facilities) are independent of map scale and of chart function.

Aeronautical information was first represented on maps as overprints of existing land maps. Conventions soon became established, as is often the case in international aviation, and many of these have been recognised by ICAO for use on charts covered by their standardisation agreements (Meine[5]; Anon[654]). The military mapping agencies use similar sets of symbols.

In most cases, aeronautical information is abstract or verbal in nature and does not lend itself readily to pictorial, mimetic or iconic coding. Many of the symbols used are therefore geometric, verbal, related object or part of the whole, in the classification terms adopted by Koponen et al.[29]. Consequently, in comparative studies of map symbols such as Koponen et al.[29] and Taylor[100], aeronautical information tends to compare unfavourably with topographical information on measures of association value, identification performance etc. While unfavourable comparisons with pictorial symbols may be inevitable, the major concern of human factors is that they should be minimised by selecting the most effective symbol that can be used. Unfortunately there is no objective evidence that the conventional symbols for representing aeronautical information are the most effective, beyond the fact that they are in common usage.

It can be argued that the factors which influenced the design of symbols for aeronautical information as overlays on early topographical maps and which to a great extent determined current practice, are not relevant for some of the more special purpose maps used in contemporary aviation. Colour coding is an example. Aeronautical information on most aviation maps is shown in dark purple/blue colours, sometimes known as Electric Blue. Electric blue was probably

first chosen for aeronautical information because it contrasts well when overprinted on the area colours used for natural features on topographical maps (greens and browns) and because it retains its contrast and darkens under red cockpit lighting, unlike say red or yellow. Blue has since become recognised as the colour most likely to be associated with aeronautical information (Van der Weiden and Ormeling[501]) and ICAO recommend dark blue as the preferred standard colour for aeronautical data (magenta is an alternative). While there are good reasons for continuing with this practice for aeronautical information generally, there are individual items of important aeronautical information that might benefit from coding in more conspicuous, attention-getting colours. Obstructions are portrayed in red on the popular RAF Low Flying Chart and on maps for radar map matching (Barratt et al.[345]). Dark blue narrow line features, such as power transmission lines tend to be seen as black (small field tritanopia); coding in red seems to avoid this and prevents potential confusions with black line features. There is, of course, good evidence that red light legibility is no longer an important aviation map requirement (Taylor[348]), as discussed in Chapter 5c. A similar argument applies to the colours used on instrument navigation charts, terminal area charts etc. Most are printed in black, blue, green or magenta, usually in just two colours, rarely in more than three. Costs may limit the numbers of colours, but a more effective selection could probably be made if the designers disregarded convention and the dubious red light legibility requirement.

Aeronautical information continues to be incorporated on visual navigation charts as an overprint, added to existing topographical maps, (e.g. UK Ordnance Survey 1:50,000 Air Overprint). This creates problems in achieving the correct visual balance between information categories and, because of its high contrasts, size and overlap with topographical data, aeronautical information tends to receive a relatively higher emphasis than is probably warranted by its comparative importance to the user. On some maps, aeronautical information could quite validly be relegated to "underprint" status (e.g. Helicopter Tactical Maps).

Ideally, aeronautical information should be taken into account in the design of the topographical base. Alternatively, revisions to the coding of topographical information should be considered to improve the accommodation of the aeronautical overprint. Electric blue obstruction symbols, for instance, may be more effective against a yellow town infill than against the black stipple infill found on many land maps. A further consequence of adding aeronautical information afterwards on a piece-meal basis, is that the map can very easily become exceedingly cluttered in highly developed areas, to the detriment of both topographical and aeronautical information. The clutter caused by an air overprint is a function of the scale of the map; low flying information causes more clutter on the 1:500,000 TPC than on the 1:250,000 JOG. The 1:500,000 RAF Low Flying Chart, based on the TPC, alleviates the clutter problem by using an unconventional multi-coloured low flying overprint. Multi-coloured overprinting achieves greater visual separability than monochrome shape coding in conventional electric blue, but it is important that its relative emphasis corresponds with the relevance of the information to the map user.

While the practice of overprinting aeronautical information on topographical information tends to emphasise the former and subdue the latter, Lakin[340] found some evidence from aircrew that the visual priorities should probably be reversed for some classes of aeronautical information on the 1:250,000 JOG-Air. Topographical features occupied the first four positions in a rank ordering of the importance of features in flight; aerodromes ranked 6, power lines and obstructions ranked 7 and 8 respectively, aeronautical information ranked 12, and electronic navigation aids ranked 14 out of a total of 16 features. Different priorities were assigned for flight planning: aeronautical information and obstructions were slightly more important for planning than in flight, whereas power lines were more important in flight. It was concluded that the consistent low ranking of electronic navigation aids and magnetic information indicated that they should be considered for exclusion from the map in the future.

Taylor[222] obtained subjective assessments of the usefulness of eighteen 1:250,000 scale maps for LAHS navigation and found no preference among aircrew for maps with radio aids information, controlled airspace and danger areas. He added that the experimental method was probably not sensitive to these differences which were visually insignificant compared with other topographical content and coding variables. The OS 5th Series M523 Decca Chart (GSGS 5030) with the extensive Decca lattice overprint was also included in the study and was rated least acceptable of all the eighteen maps tested by both pilots and navigators. It was concluded that the topographical base was irretrievably congested by the excessive clutter of the lattice, and that this rendered the map virtually useless for visual navigation purposes.

One way of avoiding the clutter problem is to print aeronautical information on the back of the sheet, or on a separate sheet from the topographical information (e.g. Koponen et al.[29]). This has the disadvantage of making correlation of the two kinds of information difficult, particularly during the VFR-IFR transition and when printed on the back it complicates the problem of folding the map so that both sides are easily read. When the user's tasks require that both topographical and aeronautical information are read together, integration on the same sheet should be preferable provided that the relationships are easily perceived and that clutter is minimised.

It should also be recognised that radio navigation facilities, air traffic control, etc are unlikely to be available during hostilities. For low level attack missions the only available aeronautical information likely to be used by pilots is information regarding obstructions, aerodromes and radio facilities, sufficiently visible on the ground to facilitate visual referencing (McGrath[339]). For this reason, war stocks of military aviation maps need not be printed with controlled airspace, danger areas etc., thus reducing the clutter problem.

With regard to the design of symbols for individual classes of aeronautical information, the literature offers surprisingly little guidance to the cartographer. Koponen et al.[29] commented on the relative legibility of symbols for

aeronautical information on the World Aeronautical Chart and Whiteside and Roden[31] reported a limited study of aerodrome symbols. The readability of numerals on Approach Charts under bright and dim luminance conditions has been studied by Welsh et al.[656]. Several comparative evaluations of aviation maps include different symbols for aeronautical information, but effects are mostly confounded with topographical context variables (Koponen et al.[29]; Chisum[408]; Taylor[100,657]; Rasmussen et al.[658]). Marsetta and Shirtleff[560] did not include aeronautical information in their study of the legibility of military map symbols. Broader issues concerning the design of aeronautical charts and flight documentation are discussed by Watkins[383] and Taylor[659].

Aerodromes

Information on aerodromes is of great operational importance. In addition to being used for take-off and landing, aerodromes can be very distinctive from the air because of their size, contrast and often exposed location, and they can be positively identified from the runway pattern, thus making them ideal visual checkpoints. An aerodrome may need to be located quickly in an emergency, and during hostilities it may be a target or a subject of reconnaissance.

It is impractical to show on maps all the details of aerodromes and their facilities that are required for take-off, landing and the ground movement of aircraft. Information on aerodromes appears in a variety of different sources including maps, charts and documentation, in different amounts of detail. Generally, large scale maps give more information than small scale maps. Instrument Approach Charts (IACs), Terminal Approach Procedure Charts (TAPs), Landing Charts, Aerodrome Charts and Standard Instrument Departure Charts give the most detailed cartographic information, showing aerodrome movement areas, stopways, taxiing guidance aids, hangars, terminal buildings etc. Runways are also drawn in detail on Aerodrome Obstruction Charts. Detailed information on hours of opening, runways, communications, navigational aids, and ground services is issued in written form in documentation known as En Route Supplements, Aerodrome Briefings or Flight Information Publications (FLIPs).

All aircrew should have ready access to FLIPs or equivalent documentation on aerodromes for flight planning, and copies will normally be carried on the flight deck. Providing detailed aerodrome information on maps for en route navigation would be an unnecessary duplication for most purposes, even if it were cartographically feasible. Furthermore, the frequency with which the information changes cannot be accommodated by normal map revision cycles. Aircrew would inevitably find themselves using out-of-date information; this would be untenable for flight safety reasons. Maps for en route navigation need only show the aerodrome layout, drawn to scale if possible or otherwise depicted by standard symbols, to facilitate visual identification. Other information should be limited to a few relatively permanent, unchanging characteristics, such as the aerodrome name, the length of the longest runway, the nature of the surface and its elevation.

Documentation on aerodrome facilities is likely to be read on the flight deck and it should be designed to be legible under adverse airborne viewing conditions. It should also be organised in a manner that facilitates speedy access and information assimilation. While not exactly a cartographic problem, the responsibility for compiling, printing and issuing such documentation often rests with cartographic agencies. In addition to maximising contrasts and ensuring adequate type characteristics, Gestalt principles of grouping, symmetry and alignment can be used to design the format of paragraphs, margins, headings and type faces so as to improve perceptual organisation and increase reading speed (Taylor[659]). Time can be an important factor when making an emergency diversion to an unplanned aerodrome.

On large scale cartographic representations such as Aerodrome Charts, the aerodrome is normally drawn in plan with minimum generalisation of detail. Revision frequency and high costs usually limit printing to one colour, normally black or electric blue for reasons already discussed, and the low complexity and low information density mean that increasing the number of colours is unlikely to lead to substantial increases in legibility. For most purposes, adequate visual separability can normally be achieved by using a combination of line symbols and solid and screened tints. Type characteristics should conform with minimum airborne legibility requirements. Aerodrome plans are included on the face of many TAPs and IACs, alongside plan and profile views of the approach procedures. This can result in an unsatisfactory cramped representation and the aerodrome plan may need to be printed on a separate sheet to ensure adequate legibility. For this reason, RAF TAPs have recently adopted a revised format with separate Terminal Approach Charts and Aerodrome Plans. Proliferation of cartographic products is often an undesirable but necessary consequence of operational legibility requirements.

On small scale maps aerodromes are shown with the runway pattern drawn to scale with or without field limits, or in a standard symbol, a circle of fixed diameter (e.g. 6,000 feet scaled equivalent on ONC) with the pattern superimposed, drawn to the same scale as the circle to facilitate judgements of runway lengths. Positive symbol formats – solid lines against a light background – are recommended by ICAO for secondary aerodromes on Approach Charts and for runway patterns drawn to scale elsewhere. They are used as the standard symbol on the JOG for aerodromes with unknown field limits and for disused runways, and they are used as the standard symbol on the ONC for major aerodromes. A negative format – a white pattern with a dark solid shape – is recommended by ICAO for principal aerodromes on Approach Charts and for standard aerodrome symbols elsewhere not drawn to scale. It is used on the JOG for aerodromes drawn to scale with field limits shown and on the TPC for major runways.

In general, negative formats tend to be more conspicuous and less affected by background clutter than positive formats. This visual priority should correspond to the operational priorities of aerodromes on maps where both

positive and negative formats are mixed, such as on ICAO Approach Charts and on the JOG. Contrasts for runway patterns in positive format standard aerodrome symbols should be maximised by clearing the interior of the circle of area tints (layers, vegetation, etc). This practice has the added advantage of increasing symbol conspicuity in relief areas by virtue of the attention-getting white coding. Negative formats showing aerodrome field limits reduce contrasts for other information within the symbolised area, such as contours. For this reason, they are unsuitable for large scale topographical maps such as at 1:50,000 scale, where they might obscure information that is useful for the low level helicopter pilot. On the other hand the enclosed shape provided by the negative format has a unifying effect on the symbol elements and could be justified on Gestalt principles of unity and closure.

In an experiment concerned with the legibility of standard ICAO and RAF aerodrome symbols (circles) without runway patterns, Whiteside and Roden[31] found that subjects could locate filled-in solid black circles quicker than outlined circles in black or red, under white tungsten illumination. Red outlines produced significantly better performance than black outlines but red was regarded as an unacceptable coding because it lost contrast under red cockpit lighting. Koponen et al. (a)[29] and (b)[331] strongly favoured showing runway patterns as the most meaningful symbol for aerodromes and regarded the basic standard circular airport symbol as comparatively poor. The poor associational value of geometric coding must also be a criticism of the standard ICAO distinction between military and civil aerodromes: small peckings of the circular outline for civil aerodromes at the four major compass bearings, double line circle for military aerodromes. The standard technique of adding an anchor to the circle for seaplane bases (related object coding) was considered to be more acceptable by Koponen et al.[29]; adding an H (verbal coding), the standard practice for indicating heliports, was not considered but might fall into the same category as seaplane bases.

Judged on conventional legibility criteria (size, contrast, etc) the discriminability of the land/water and civilian/military aerodrome codings must be near threshold for critical viewing conditions (vibration, low intensity illumination) for low resolution map display systems (CRTs, MMDs), unless the physical dimensions of the symbols are considerably exaggerated over those that are normally recommended. However, for most practical purposes discrimination difficulties with these symbols are unlikely to cause serious operational problems. Both Koponen et al. (b)[331] and Taylor[100] included aerodrome labels in comparative evaluations of map legibility but neither came to any specific design conclusions, other than the general plea for maximising contrasts and selecting type characteristics according to the worst conditions of viewing.

Obstructions

Information on obstructions, features having vertical significance in relation to adjacent and surrounding features (radio masts, water towers, chimneys, tall buildings, etc) fills a dual purpose on aviation maps. Obstructions, by definition, are a hazard to the safe passage of aircraft, but they may also act as visual checkpoints if they are distinctive when viewed from the air. Not all obstructions are easily detected from the air and their portrayal on maps serves as a valuable cautionary and anticipatory device, particularly during flight planning, (Lakin[340]). All aviation maps should portray obstruction information if there is a possibility that the user of the map may be flying close to the ground. At scales smaller than 1:1,000,000, used mainly for high altitude navigation, the requirement for obstruction information is minimal, but on Terminal Approach Charts (TAPs, IAPs, etc) and on maps used for navigation at low altitudes (Helicopter Tactical Maps, JOG, TPC and OBC) obstruction information is vital for flight safety reasons. It would seem to be in the interests of flight safety to portray obstructions on all cartographic products used in the air, particularly since there are so few serious cartographic problems in doing so. Major obstructions are relatively infrequent and they can be represented by point symbols without creating unacceptable clutter. Obstructions are also relatively permanent features and their portrayal does not require frequent revision. At present, obstructions are shown on all ICAO maps except Aerodrome Charts: elevations for selected features constituting a hazard to air navigation may be shown on Radio Navigation Charts and Terminal Area Charts, particularly hazardous or prominant relief features are emphasised on Plotting Charts; all other ICAO maps and charts include significant obstructions as a standard requirement.

Obstructions are useful as visual checkpoints when they are large solid structures contrasting well against the horizon at low altitudes and when lighted at night. Aircrew ranked obstructions (lighted) as equal fifth along with motorways on the ratings of the importance of selected features for fixing positions during low altitude visual navigation at night (Taylor[348]). Despite this, aircrew are discouraged from planning routes near to obstructions, partly because they are unlikely to be lit at night during hostilities and partly because meteorological conditions and geographic disorientation can reduce the probability of detection. Furthermore, once detected, a positive identification of an obstruction can rarely be achieved without reference to other features in the vicinity. Since obstructions that have been identified cannot be overflown without hazarding the aircraft, their value as checkpoints is restricted to providing only a general confirmation of position rather than an accurate position update.

The significance of obstructions for the map function should determine the criteria used for their selection. On ICAO Aerodrome Obstruction Charts, all obstructions are regarded as significant that lie in the take-off flight path area and project above a plane surface with a 1.2 per cent slope and a common origin with the take-off flight path area. On ICAO Instrument Approach Charts obstructions are shown when they are the determining factor in the obstacle clearance limit for the area. On ICAO 1:500,000 and 1:1,000,000 scale maps for visual navigation, obstructions of 100 metres (300 feet) or more are regarded as sufficiently significant to be portrayed. In military series, (60 metres) 200 feet AGL or above is used as the selection criteria for the 1:250,000 JOG, the 1:500,000 TPC and 1:1,000,000 ONC. Strict adherence to an exact minimum figure for inclusion simplifies the cartographer's task. However, from an

130

operational point of view, it can have disadvantages when it causes obstructions to be omitted that are below 200 feet AGL in height, but on hilltops or other prominent locations. Ideally, there needs to be some flexibility in the selection criteria that will allow known hazards to be included even though they are below the 200 feet limit. At present, the cartographer has to misrepresent the height at AGL in order to include significant small obstructions,.

Two hundred feet would seem to be a logical selection criterion in that the low flying system assumes a minimum ground clearance of 250 feet for jet aircraft. Aircraft wishing to fly below 250 feet must obtain special permission to do so. As data collection techniques improve and operational requirements become better defined, it can be expected that for certain areas of high density low flying activity, the minimum height for portrayal of obstructions will be reduced to 150 feet or below. However, investigations have shown that a 150 feet minimum dramatically increases the number of obstructions to be shown in developed regions and that it may be untenable on small scale maps because of clutter. Helicopter tactical operations involve flight at low altitudes down to 50 feet AGL or less. At present, only obstructions over 200 feet are shown on the UK 1:50,000 scale air overprint, largely because of difficulty in obtaining the additional data required for a more comprehensive portrayal.

The method of portraying obstructions recommended by ICAO, and used on the JOG, is an electric blue inverted 'V' line drawing geometric symbol with a dot at the centre of the undrawn base line corresponding to the exact location of the feature. A similar, but more solid, more pictorial inverted 'V' obstruction symbol is used on the TPC and ONC, and for exceptionally high obstructions (1,000 feet or over) by ICAO.

The line drawing obstruction symbol has low associational value and it is unlikely to meet the minimum legibility requirements for symbols in complex, low contrast backgrounds and under difficult viewing conditions. It can also be criticised for its similarity to the electric blue line for power transmission lines. Although there is no objective evidence on the efficacy of this symbol, Lakin[340] found that aircrew users of the JOG ranked the criticism "obstructions do not stand out well" as the fifth most serious of sixteen named criticisms of the map. Solid contrasting pictorial symbols, such as those used on the TPC and ONC are essential for topographical maps and there can be no disadvantage in adopting the same symbol for all maps and charts. A solid red triangle symbol has been used on maps for radar-map matching (Barratt et al.[345]). Although this symbol is conspicuous and has the adequate size and contrast for degraded viewing conditions, it has the disadvantage of not explicitly indicating the feature's location, (centre of base line). Koponen et al.[29] regarded as poor the geometric, unfilled, triangle symbol for obstructions used on early World Aeronautical Chart (WAC) series with a separate dot below the triangle to indicate the feature's location.

Distinctions between single and multiple obstructions should be made to facilitate visual identification. Multiple obstructions are normally shown by two overlapping obstruction symbols. This practice may cause confusion for the inexperienced map user who has not read the legend and who assumes that the symbol means that only two obstructions are present on the ground, and no more. Under degraded viewing conditions the amount of overlap between the two symbols will determine the discriminability of single and multiple obstruction symbols. The space between the tops of the two symbols is the critical physical dimension and it must be sufficient to be resolved under all viewing conditions. Visual identification can also be facilitated by indicating obstructions that are lighted at night. Unfortunately, the method recommended by ICAO – short lines radiating from the tip of the obstruction symbol may be difficult to discriminate under difficult viewing conditions. A small circle centred on the top may be a more legible alternative.

For the purposes of estimating obstacle clearance altitudes, the absolute elevations of obstacles should be shown in feet, giving both the height above mean sea level (MSL) and the height above ground level (AGL). The standard practice shows height above MSL, usually the larger value, situated above height AGL, the latter given in parenthesis. There are instances of significant obstructions that are situated on ground below MSL where the height AGL is greater than the height MSL, but these are few. Identical type face is used for both sets of numerals. Thus the identity of the numerals, above MSL or AGL, coded by a positional cue (upper or lower value), by a shape code (no parenthesis or parenthesis), and by the relative magnitude of the numerals (greater or lesser). This triple redundant coding should be sufficient to minimise the possibility of confusions.

On the ONC, the procedure described above is used to code the height of pictorial symbols for landmark features that have vertical obstruction significance. Whether this should become standard practice on all aviation maps or whether such features should be coded by standard obstruction symbols rather than pictorial landmark symbols depends on the advisability of aircrew treating distinctive obstructions as potential visual checkpoints. Classifying significant obstructions as distinctive landmark features will undoubtably encourage aircrew to treat such features as potential visual checkpoints, with all the inherent dangers of doing so in poor visibility etc. This is contrary to the principles of flight safety. In such cases, the correct emphasis on caution and landmark distinctiveness may be achieved by labelling standard obstruction symbols with the feature's name (e.g. chimney, mast, smokestack, etc.), a procedure also used on the TPC and ONC.

Power Transmission Lines

Power transmission lines constitute a serious navigational hazard for low flying aircraft. They are often difficult to detect from the air because they are small, and lack contrast and because the pylons are open rather than solid structures. Many are painted green to blend in with the background at the behest of environmentalists, and unlike significant obstructions they are not lighted at night. Whereas obstructions are often conspicuously built on high ground and

hill-tops (e.g. telecommunication masts) power lines tend to follow the most conventional route, usually along valleys, and consequently they are frequently hidden from the direct line of sight by terrain masking. Where they cross high ground, their location is often indicated by the broad swathes that need to be cut through forests to accommodate them. Generally, power lines are hazardous, and difficult to detect and identify positively. Because they are line features giving only one-dimensional location cues, they are of limited use as visual checkpoints in conjunction with other distinctive features. Once detected, distinctive power lines may be used as line following features, but continuous visual contact is often difficult to maintain and along-track power lines are likely to lead to an across-track power line. Therefore, line following must be carried out with extreme caution. Thus the principal function of power transmission lines on maps is to act as a cautionary device. Aiding navigation is a relatively minor function. Selecting and coding of power lines according to navigational significance is unlikely to be an important requirement. If selective representation were to be contemplated it should be based on the seriousness of the hazard which is determined by factors that are negatively correlated with navigational efficacy, such as complexity, irregularity and high detection difficulty.

Barnard et al.[129] reported that wires of all kinds are regarded as the most dangerous hazard to low flying helicopters, particularly those that cross valleys and gaps between woods and buildings. Despite this, wires are regarded as useful navigational cues during day transit and nap-of-the-earth helicopter flying. This is probably because helicopters fly at lower speeds than fixed wing aircraft, allowing more time for detection. Wires that are already shown on the map are invariably highlighted by aircrew and if a reconnaissance is possible all other wires which could prove dangerous are added. Some squadrons conduct regular "wire recces" in local areas where low flying takes place to check on recent changes and additions to wires in the interests of flight safety. Many units keep an up-to-date record of wires and other hazards on an annotated "master" map of the local low flying area displayed in the flight planning room.

At night, moonlight may be reflected off the metal surfaces of power lines and pylons, occasionally facilitating their detection. Barnard et al.[129] reported that power lines could be used for helicopter navigation in above moderate moonlight but aircrew rated them relatively low on utility at night compared with daylight. Similar low ratings of the visual utility for fixing positions by power lines at night were obtained by Taylor[348] from the crews of fixed wing and rotary wing aircraft.

The cartographic representation of power transmission lines is complicated by inadequate data sources and difficulties in specifying selection criteria. Power transmission lines are depicted on most large scale land maps, but the representation is highly selective and often considerably out-of-date. The basis for selection is usually the nature of the support not its height or size, e.g. steel pylons are shown, wood pylons are omitted. Many new power lines can be erected during a normal land map revision cycle and the quality of information available for a revision varies considerably between the different authorities that are responsible for erecting the structures. Whatever selection criterion is adopted by the aviation cartographer, it is important that the representation should be kept up-to-date, and that new power lines are added without delay. Revision cycles for power line information should not therefore be tied to revision cycles for other relatively permanent topographical information.

The UK 1:50,000 Series has recently acquired a power line (and obstruction) overprint for aviation purposes, particularly for low level helicopter operations. The impracticality of showing all wires, the ultimate helicopter requirement, has been demonstrated by Barnard et al.[129]: complete representation of wires in developed areas produces totally unacceptable clutter because of their high frequency. All lines on steel supports are shown on the 1:50,000 overprint because of their radar significance, together with all wires with more than 80 foot ground clearance. To achieve this all the wires, including telephone wires, have to be inspected and checked where they pass over valleys. Where part of the line exceeds 80 feet, this has to be shown on the overprint as an isolated line extended slightly in each direction beyond the critical length. A three level classification of power lines (275 kv; 132 kv; other minor lines) is indicated by three line widths (32 thou; 18 thou; 12 thou) Barnard et al.[129] reported that user comments on the power line and obstruction overprint were generally favourable, although some had pointed out that omitted lines below 80 ft were potentially the most dangerous.

On aviation maps governed by ICAO and on military series, the principles for the selection of power transmission lines are broadly similar to those for obstructions. "Prominent" power transmission lines are shown on ICAO 1:1,000,000 and 1:500,000 maps, although prominence is not defined. Both the JOG and TPC attempt to give a comprehensive coverage of major power lines over 200 feet. The ONC coverage is noticeably less comprehensive than the larger scales. A cautionary note is given in the JOG legend to the effect that although the most reliable sources available have been consulted, there can be no assurance that all the power lines are shown.

Methods of coding power transmission lines vary on different aviation maps. Most use electric blue colour coding, including ICAO maps; the ONC and land maps use black. ICAO recommend a wavy blue line interrupted by T shaped pylon symbols at regular intervals. The UK 1:50,000 power line overprint, and both the JOG and TPC use a straight line interrupted by solid pictorial pylon symbols. The pylon symbols do not correspond to actual pylons on the ground and there is no requirement that they should do so. A broken dashed line with dots at regular intervals is used on the ONC.

Taylor[100] compared the legibility of the JOG straight line symbol with a zig-zag pattern. Both were interrupted by the standard pylon symbol, both were in the same JOG standard line width, and both were coloured in electric blue. The non-standard symbol produced a statistically significant ($p < 0.01$) increase in identification performance under

degraded (projected image) viewing conditions; the straight line symbol was most frequently confused with rivers on several trials. It was concluded that while the addition of shape coding was an improvement, the modified symbol was visually 'noisy', it created clutter, and caused unacceptable ambiguity over the feature's location.

It should be possible to achieve adequate conspicuity and identification performance for power transmission line symbols from colour coding and the intermittent pylon symbol, without resorting to ambiguous shape coding of the line elements. Contrast, size and associational value requirements favour the JOG/TPC pictorial pylon symbol in preference to the ICAO geometric T. Improved identification performance could probably be achieved by increasing the size and the frequency of the pylon symbol and by increasing the width of the line elements to the sizes used on the OS 1:50,000 overprint. An increase in line width will improve the perception of the colour code, and improve the resolution of the line under difficult viewing conditions. Furthermore, a more conspicuous colour probably could be employed, such as a high contrast magenta or red.

Radio Facilities

Information on radio facilities is required on aviation maps to facilitate position finding when visual referencing is impossible or insufficiently reliable for safe and accurate navigation, such as during approach and landing. The main radio aids for aircraft navigation are non-directional radio beacons (NDB), VHF omni-directional radio range (VOR), distance measuring equipment (DME), UHF tactical air navigation facilities (TACAN), ranges and broadcast stations. Collocated, multiple facilities are common, e.g. VOR/DME and VOR/TACAN (VORTAC). In order to use radio facilities, the aircraft must be fitted with the appropriate instrumentation. Given this, the pilot or navigator needs to know where the facilities are located with respect to his planned route – many are located on or near airfields or on airways for en route navigation – and he needs a variety of other information such as the type of facilities provided, identification names, call signs, contact frequencies and times of operation. This information can be provided on topographical maps, charts or in flight information publications.

Radio facilities information is shown on ICAO Plotting Charts, Radio Navigation Charts, Terminal Area Charts, Instrument Approach Charts, 1:1,000,000 and 1:500,000 Aeronautical Charts, Visual Approach Charts (where they constitute landmarks or obstructions) and Landing Charts. Instrument Approach Charts give the most detailed information (e.g. distance to the aerodrome); large scale maps tend to show the least information to minimise clutter. The military JOG, TPC and ONC Series show radio facilities by the type of facility and identification name only, partly because of clutter and partly because, like all aeronautical information, the penalty of giving detailed data is that a more frequent revision cycle is necessary to keep up with changes. Frequently changing information, such as times of operation, is best shown on products that are relatively cheap to produce and easy to revise such as TAPs and IAPs. Some authors (e.g. Lakin[340]) argue that radio facilities information on large scale topographical maps is highly redundant and rarely used by aircrew, and that it could be excluded without seriously reducing operational efficiency.

A set of standard geometrical symbols is widely used to represent NDB, VOR, DME, VOR/DME, TACAN and VORTAC facilities (Fig.5). A small circle with a central dot forms the basic radio facility symbol. This is used for NDBs, sometimes surrounded by a circular area covered with a dot stipple, and for multiple facilities other than VOR/DME and VORTAC. A hexagon symbol is used for VORs. A square is used to represent DME facilities. The hexagon and square have the same height and width so that they can be superimposed for co-located VOR/DME facilities. The TACAN symbol is a modified VOR shape. This becomes apparent when the TACAN symbol is partially filled-in to indicate co-located VOR/TACAN (VORTAC) facilities, revealing the basic VOR shape inside the VORTAC symbol.

Since these symbols have no pictorial, mimetic qualities, their meanings must be memorised or decoded by reference to the legend. Confusions and misidentifications are likely to arise during the learning process, but there is no evidence that the symbols have been designed to minimise such errors. Whereas the discriminability of the symbols possibly could be improved by redesign and empirical testing, it is unlikely that meaningful pictorial qualities could be added to the symbols to improve their identification significantly because of the essentially abstract nature of radio facilities. Furthermore, co-located facilities would be difficult to represent with anything other than abstract geometric shapes. Even with the present symbol set, there is a limit on the number of co-located facilities that are symbolised: VOR/DME and VOR/TACAN are accommodated but NDB/VOR, NDB/TACAN, VORTAC/NDB and VOR/DME/NDB are not. The ideal symbol set would include all possible collocated facilities.

Radio range symbology, fan markers and compass roses, may be associated with the facilities symbols. On most maps and charts the name of the facility is shown in a rectangular box attached to the facility symbol by a leader line. When the standard symbols are not used, either because multiple facilities are present or because the facilities are located on an aerodrome, the box will also contain lettering to identify the types of facilities provided. Call signs and frequencies may also be included. The JOG does not use geometric symbols and all radio facilities are identified by lettering. The use of boxes and lettering on topographical maps was criticised by Koponen et al. (a)[29] and (b)[331], mainly because of inadequate sizes and contrasts. Taylor[100] obtained only moderately acceptable identification performance for radio aids lettering on the JOG. A small increase in stroke width (0.18 to 0.25 mm) failed to improve legibility, but this may have been confounded with the effects of reduced contrasts caused by the addition of a light blue tint to the boxes to assist information location. Boxing serves to unify the elements and by so doing it may reduce map reading time, but in general it seems that a substantial increase in the size of standard lettering is required to ensure legibility on topographical maps under cluttered, low contrast conditions.

Airspace Information

Two kinds of airspace information are provided on aviation maps:–

(1) Information related to air traffic services, i.e. Flight Information Regions (FIR), Aerodrome Traffic Zones (ATZ), Control Areas, Airways, Controlled Routes, Uncontrolled Routes, Advisory Areas, Advisory Routes (ADR), Control Zones, Reporting Points, Compulsory Corridors, Air Defence Identification Zones (ADIZ), Ocean Control Areas (OCA), Buffer Zones, Low Flying Areas, Low Flying Routes;

(2) Special use or restricted airspace, i.e. Prohibited, Alert, Danger, Caution and Restricted Areas.

The type of airspace information shown depends upon the purpose of the map. Large scale topographical maps intended primarily for visual navigation purposes and charts for approach and landing (IAPs and TAPs), show very little airspace information, e.g. ADIZ on JOG; medium and small scale military topographical maps may show all Special Use Airspace and Low Flying Routes; Terminal Area Charts and Radio Navigation Charts show air traffic services information.

Airspace areas are usually large and simple in shape. Most can be adequately represented by boundary line coding supplemented by hachuring or vignetting on the interior side of the area. The line should be bold and distinctive, and the vignetting or hachuring subdued to minimise obscuration of other detail. Shape coding and discontinuity can be added to the boundary line to distinguish between different kinds of area. Area tints probably give more stable figure-ground segregation than boundary lines alone (Taylor[659]), but they are inadvisable when they are likely to cover large regions of the map containing other information that is relevant to the user. If tints are necessary they should be as light as possible to minimise the loss of contrast for lettering and topographical information. On some charts, airways are distinguished by an area tint, and non-airways are left clear. Most aircraft using such charts will be flying along the airways and information outside these areas is relatively unimportant. Contrasts should be greatest where the information that is being used is densest, along the airways, and thus non-airways areas rather than airways should be tinted.

Information on prohibited, restricted and danger areas is vitally important for low flying aircraft operations. Restricted areas are prominently represented on the RAF 1:500,000 Low Flying Chart by coding in red. Red colouring has strong connotations of danger and its good attention-getting properties make it preferable to electric blue when red cockpit lighting is not a design constraint. Low flying is often prohibited over built-up areas and nature reserves and the method of coding should be chosen to minimise the obscuration of underlying features, particularly town shapes. Lettering relating to airspace should be printed in the same colour as the area symbol to facilitate visual organisation and search. If the area symbol is screened or desaturated, the colour of the lettering should be solid and saturated in order to maximise contrasts and minimise legibility difficulties.

9d OTHER INFORMATION

Names

Names on maps denote a variety of point locations, lines, areas and regions. They are associated with cultural, natural and abstract features including communities, political boundaries, administrative regions, deserts, forests, mountains, peaks, roads, rivers, estuaries and lakes. In a world-wide map series, the same name may be used to denote several different features. Yet within a given sheet, most names denote a unique feature. Thus, names on maps provide a highly specific verbal reference system (Keates[120]) that can be used to identify locations and features in place of, or in conjunction with, spatial co-ordinate reference systems.

Names are particularly useful for identifying line features such as rivers and areas such as mountain ranges, which are difficult to describe solely in spatial terms. Name references are also the method used in normal verbal communication to describe locations. As a result of their common usage in text and speech, names are often highly meaningful and have high associational value. These factors are important in the storage and retrieval of information from memory. Thus, a verbal description of a location in terms of names of associated regions and features will tend to be remembered better than a set of abstract grid co-ordinates. Un-named locations must be specified in spatial terms, but by also stating the name of the region and the names of features close to the position, the originator of a communication can guard against major locational errors which easily arise from confusions, mishearings and misreadings of grid alphanumerics (Taylor and Hopkin[151]).

Names on maps may have historical, sociological, and geographical significance as well as a locational reference function. Numerous names can cause unacceptable clutter for aviation purposes (Taylor[222]). Furthermore, the more names that are portrayed the longer it takes to find a specific name (Phillips et al.[568]). In designing maps for aircraft navigation, it is important to distinguish between the different functions of names on maps, to exclude unnecessary names, and to avoid over-elaborate methods of classification that are not relevant to the primary task. For some aviation tasks, names may be redundant or irrelevant information. McGrath et al.[132] found that visual navigation performance in simulated low altitude high speed flight was not impaired when place (community) names were removed from a Sectional Aeronautical Chart. Navigation by visual referencing and by similar tasks such as radar-map matching, makes little use of the names of features and relies almost entirely on the shape, pattern and sequence of features. On the other hand, names are useful for general orientation purposes and for tasks involving verbal communications, for

example in two seat operations (pilot and navigator), in formation flight, and in ground support operations under forward air control. Briefings usually make some reference to the names of major communities for tactical as well as general orientation purposes; during flight planning, checkpoints, IPs and dropping zones etc. will be memorised by visual and verbal encoding, utilising names where they are shown, or even creating imaginary names when they are not. It is difficult to envisage any aviation map reading task that would benefit from the omission of all names from maps. It is equally true that no tasks require the high density and complex classification of names found on many school atlases.

As a general rule, the density of names should reflect their frequency of usage. Long names and names that are difficult to pronounce, such as names in foreign languages, should be either transliterated or omitted because otherwise they are unlikely to be used, even sub-vocally. Names in close proximity are likely to be redundant for referencing positions and most tasks will be facilitated equally well by an evenly spaced selection of names. Charts intended for navigation purposes need only portray the names of major communities, rivers and regions that are likely to be used for general orientation.

Principles of information presentation relevant to the coding of names on maps have been discussed in Chapter 8 in the section on typography. The legibility of names can be influenced a great deal by where they are placed on the map. It has been contended that for each name there is one optimum position on the map (Imhof[158]) and the problem is therefore to formulate rules which specify how it may be determined. There may sometimes be a conflict between the requirements for locational precision and for the position that affords the best legibility on grounds of contrast or clutter. Unlike topographical symbols, names are abstractions with no physical equivalent on the ground. They are related to topographical features or areas, and in positioning names, the cartographer's main task is to show this relationship while retaining legibility. Names relating to points should be positioned to indicate their locations. Names relating to linear features should be positioned to indicate the orientation and length of their referents, such as rivers. Names relating to areas should designate the form and extent of the area.

It is good cartographic practice to print names along the West-East axis of the map, reading from left to right when the map is orientated North-up. Maps are usually held track-up during navigation, but North-up is the most frequently used single orientation during briefing, planning and map study. This is probably because most individuals organise their mental maps North-up and find they can assimilate new information better when it is presented in the same orientation. Names are easiest to read when they are arranged from left to right along the normal reading axis; reading difficulty increases as the names are oriented off the normal reading axis and they become extremely difficult to read when the orientation exceeds 90° from the horizontal (i.e. inverted). Groups of names arranged in the same orientation are easier to read than names placed in a variety of orientations (Robinson and Sale[95]). Inter-letter spacing and letter size can be varied to designate the extent of area features, such as administrative regions or states, but excessive spacing makes the characters difficult to read as a single word. As a general rule, spacing should be minimised, repeating names if necessary, and where the continuity of names conflicts with other topographical features such as lines and tones, the topographical features should be interrupted rather than the names.

The requirements for typeface, weight, size and case are discussed in Chapter 8c. Guidelines established from experimental work in other areas must be treated with some caution (Bartz (b)[99] and (a)[509]; Taylor and Hopkin[151]) partly because the classification of names of maps is coded by type variables and because of the importance of search. The legibility of names for communities, peaks and rivers was compared in different type by Taylor[100]; type size and stroke width were found to have a significant effect on performance. Phillips et al.[56] found no significant difference between bold and normal weight type, and between Times and Univers type face on a number of tasks involving place names on maps; the main variables that affected performance were type size, case, complexity of the map base, and the difficulty of pronunciation of the place names. Colour coding was not included in this study but it is undoubtedly an important variable (Foster and Kirkland[660]). Phillips et al.[568] made the following recommendations for the use of place names on maps:–

(1) Type legibility must be considered in the context of the map as a whole and should depend on the relative importance of the information.

(2) The size of the type should be determined by the importance of individual names and by the importance of names in general (eight point type is easier to search for than six point type).

(3) Names set in lower case with an initial capital are easier to search for and occupy less space than names set entirely in capitals.

(4) Bold type is no more legible than normal weight type and should be avoided as it has a cluttering effect on maps.

(5) The choice of type face appears to have little effect on legibility.

(6) Names which are difficult to pronounce should be set entirely in capitals.

Contrary to the research literature, upper-case capitals are used for all place names on the 1:1,000,000 ONC; communities of first and second order of importance are distinguished by size, weight and type face. Upper-case capitals are also used for places of primary and secondary importance on the 1:1,500,000 TPC, and for primary, secondary and tertiary importance on the 1:250,000 JOG. Lower orders of importance are depicted by names in lower case with initial

capitals, consistent with good ergonomic practice. Size, weight and type face variations are also used. Five levels of importance are distinguished on the JOG, three levels are used on the TPC and only two classifications are made on the ONC.

The JOG specification calls for the maximum density of names provided that significant detail is not obliterated. Names, usually in conventional English, appear for a wide range of drainage, vegetation and relief features in addition to populated places, landmarks, railroads, roads, political divisions, and aeronautical facilities. In developed regions such as the UK this leads to an unusually high density of names. According to Lakin[340] 47% of UK JOG users favoured a reduction in the density of names so that only the more important populated places are named, and 61% considered that detailed road classification was unnecessary.

Five levels of classification by type size coding probably exceed the discrimination ability of users. It is also doubtful if there are more than three meaningful differences in the importance of communities to aviators. The research literature shows that upper case capitals are difficult to justify for other than initial letters in familiar names. However, the frequency of strange sounding names on a world-wide series and the need for standardisation probably weighs in favour of using capitals at least for the more important names. Type face variations should be replaced by size differences wherever possible. Most names are printed in black, partly to maximise contrasts and partly for printing economy. Blue is the only frequently used alternative. If the observer knows the colour of the name he is looking for, colour differences can improve search performance for names (Foster and Kirkland[660]) but as Taylor[596] has shown contrasts are a major limiting factor on the way that coloured lettering can be used.

Co-ordinate Reference Systems

Co-ordinate reference systems have been described in detail elsewhere (Chapter 2b). The GEOREF graticule or LAT/LONG system is used in aviation for most purposes and it can be found on nearly all aviation maps, including ICAO publications and the three major military topographical map series (JOG, TPV and ONC). Ground forces use the Universal Transverse Mercator (UTM) grid system; this can be found on most land map series (1:50,000 scale or larger) and on the JOG and TPC to facilitate operations in support of ground forces. Other grids such as Decca doppler lattice can be found on special purpose charts.

A co-ordinate reference system is essential on maps for tasks involving navigation and accurate position plotting. Not all charts are used for position plotting (e.g. Aerodrome Charts, Terminal Area Charts, Instrument Approach Charts) and grids may be omitted with impunity. More than one reference system on a map is unsatisfactory from a human factors point-of-view (e.g. JOG, TCC) and the task of transferring from one system to another must seem an unreasonable burden for the already overloaded pilot in low altitude, close support operations. The introduction of digital navigation systems and pocket calculators capable of converting between different co-ordinate systems may reduce this problem. As long as aircraft continue to navigate in GEOREF co-ordinates to positions given in UTM, there will probably always be some requirement for maps with both systems, if only to cover the case of navigation system failure.

The graphic elements of co-ordinate reference systems include the lettering and numbering of the grid or graticule, its line weight, graduation and colour coding, and the instructions regarding its use shown in the map border. There is very little literature that is directly concerned with research on the graphic variables of grids on maps but some guidelines can probably be generalised from work on grids in other areas. Taylor and Hopkin[151] found that the speed and accuracy of plotting UTM grid references on the JOG was not affected by the density of cartographic information around the position being referenced. Kempf and Poock[508] reported that the presence of layer tinting did not affect accuracy but decreased the speed of grid referencing. Grid referencing on maps can be very precise with the use of aids such as romers. Normally the process involves factors which are prone to error, such as memory, judgement and interpolation. Guttman and Finley[420] showed that aircrew made errors in four-figure grid references on 12% of the interpolations made in each co-ordinate. Taylor and Hopkin[151] list four different sources of grid referencing errors namely mishearings, confusion errors between divisions of the grid, number rounding, and interpolation errors.

The marked intervals on scales influence the accuracy with which interpolations can be made, though not in a linear fashion (Carr and Garner[661]). Interpolation is a function of the number of intervals and of relative distance from a main crossing grid line, and there may be sudden reversals of direction of interpolation errors (Hopkin and Woolford[662]). On the whole, however, performance of interpolation tasks is quite good, and gives an acceptable level of accuracy if the marked intervals are correctly chosen. Generally, the interval between ticks and markings should be chosen to minimise the amount of interpolation. Partitioning by very frequent grid or georef lines may not produce commensurate improvements in accuracy of interpolation, and may have the incidental disadvantage of disrupting search patterns, (Eriksen[447]). The findings from studies of reading co-ordinates on large plotting tables may not apply to maps, and in any case are not consistent. Green and Anderson[663] who required the range and azimuth of various targets to be given, found that the characteristics of the grid did not influence the time taken, but Corkindale and Cameron[664] reported that the speed of reading grid references, but not the accuracy, was affected by viewing position.

It is essential to ensure that grid lines cannot be confused with any linear features portrayed on the map, even though these may rarely be parallel to them. They must be distinguished readily under all lighting conditions from railways, power transmission lines and canals, the main features with which there is some possibility of confusion. Being straight and regular, grid lines can be comparatively thin and yet still remain readily discriminable. Thinness is a

desirable property because of the need to minimise clutter. Evidence on the discriminability and vernier acuity of line width may assist in formulating hypotheses on how much lines need to differ in width before they are reliably discriminated as different. The principles suggested by Wright[181] may also be employed. He noted that the trial and error technique and cartographic experience were often relied on when choosing suitable line widths. Available tools for line drawing are a further influence, and these are summarised by Monkhouse and Wilkinson[139] who illustrate a range of line widths, and the main varieties of line employed in cartography. If both GEOREF and UTM grids are present on the map, differences in line thickness, in conjunction with ink colour and strength, may be the most suitable means for separating them visually. The designer should aim to give greater visual emphasis to the GEOREF graticule with a subdued representation of the UTM grid, consistent with the priority of usage in aviation. This relative emphasis is achieved on the JOG and TPC by coding the GEOREF graticule in black and the UTM grid in blue. Brown and black UTM notation was compared by Taylor[596] but no significant differences in legibility were observed. Barnard et al.[129] noted that helicopter aircrew frequently highlighted grid notation by colouring the area surrounding the characters in yellow. This practice was incorporated in the design of early prototypes for the 1:50,000 US Helicopter Tactical Map, but it has been omitted on the pre-production prototypes.

Boundaries

A variety of administrative and political boundaries is shown on aviation maps, represented by black broken lines or alternating series of dots and dashes. International boundaries are highlighted on the JOG, TPC and ONC by a brown band overlayed on the black line symbol.

Boundaries are a greater problem on ground maps than on air maps, since they are not likely to be confused with any information of direct interest from the air, but may bear some similarity to relatively unimportant linear features such as paths and right of way on the ground. In general, only major political boundaries are of significance to the users of air maps. Other boundaries may be classified as types of air information if they are relevant. The presence of minor administrative boundaries on an air map may indicate that it has been adapted from ground usage, as normally such information can be excluded in the interests of clarity.

Marginal Information

Maps contain a variety of non-cartographic information in the form of marginal information or legends. This information serves an important function and, like cartographic information, it should be displayed to suit user requirements for legibility, interpretability, visual organisation and balance. However, the design and layout of marginal information does not seem to have been the subject of human factors research. The main variables have been summarised by Keates[120].

Maps are normally produced on rectangular sheets to facilitate printing and reprographic processes. Sheet size and shape vary for different series according to type of map and the method of handling appropriate to the user's task. On a given sheet the space available for marginal information depends on the projection and sheet lines employed which may or may not be rectangular, (e.g. Lambert Conformal Conical Projection). All three major topographical map series (JOG, TPC and ONC) print map information up to the north and east edges of the sheet (bleeding edges) so that adjacent sheets can be overlayed and joined accurately. This leaves space for marginal information on the bottom and left edges. Charts for aerodrome information, radio navigation, terminal areas, approach and landing are not joined, and thus they are usually surrounded by a border on all sides.

The basic elements of marginal information are the series title, sheet title, scale, an explanation of the symbols, and credits. Other essential information includes the date of the map information, the date of any revision if this is involved, the publishers, the definition of the measurement system including the vertical interval for contours and any graphic or supplementary scales. On the main topographical air maps (JOG, TPC and ONC) almost the entire vertical (left) border is devoted to explanatory notes on symbols, mostly aeronautical information. Explanatory notes on the GEOREF and UTM reference systems are given together with a sheet index plan, a glossary of terms, and an address to notify when errors are detected or when revisions become essential, say for flight safety reasons. The scale of distances is given in statute miles, kilometres and nautical miles. An elevation conversion scale (feet to metres) is given on the TPC and ONC.

With so many items of information competing for such limited space, the arrangement and layout of each component can be critical. Ideally, to reduce search time, standard formats should be followed such as that suggested by Keates[120], p 161). or by ICAO (Anon[654]). Unfortunately, the requirements of individual sheets often prevent this, such as the need for bleeding edges. Some of the basic principles governing good layout have been stated by Keates[120]. These include the need to occupy the space symmetrically, using the centre lines as guides, organising lines of text in parallel and with equal spacing, avoiding unnecessary description, and repeating essential identification information on the leading edge where it can be read when stored in a drawer without removing the whole sheet. In a series, the marginal information should follow the same standard layout and design, for the benefit of the producer as well as the regular user.

Explanatory notes on symbols should include an example of each symbol in all its variations (e.g. vignette wood patterns, roads in built-up areas) preferably against the background in which the symbol normally occurs on the map

(e.g. mud flat symbols on blue sea vignette). It might be useful to demonstrate the appearance of wood symbols against layered backgrounds. Stylised landmark symbols that rely on contextual cues for identification on the map (e.g. dams), should be shown in the legend in a sample context. Layer tints should be demonstrated in the margin. The conventional practice of using a vertical layer wedge of rectangular blocks of colour with associated height intervals may not be the optimum presentation in terms of communication effectiveness. Alternative methods may be more effective, such as the pictorial format used on the ONC for its Terrain Characteristic Tint System, and the small scale, relief only summary diagram, used on prototype Helicopter Tactical Maps.

It is important to recognise that border information is unlikely to be read by aircrew in-flight. Consequently the stringent legibility requirements for cartographic information need not be applied so rigorously. In map preparation during flight planning, map borders may be cut from the map and discarded as waste. In fact, they may only be read by the user when a new edition is issued or when the identity of a particular symbol is questioned during map study. Border information is probably more frequently consulted during aircrew training than at any other time. It is possible that this training requirement might be better met by explanatory notes set out in a small instructional leaflet or text used in conjunction with or in place of marginal information on the map.

CHAPTER 10

AVIATION MAPS AND COLLATERAL MATERIAL

The aviation map may be considered as one of a number of methods for producing an image or likeness of the surface of the earth (Imhof[636]). Other methods include photographs, drawings, three-dimensional models and sensor imagery such as radar, television and infra-red displays. Tasks that include map reading frequently involve reference to other sources of terrain information such as photographs and sensor displays, and to verbal information in the form of text or speech. The most common form of collateral information when map reading in flight is the direct unaided view of the terrain. Variations in collateral information affect map reading performance and variables in map design affect the interpretation of other sources of terrain information. The compatibility and integration of the sources of information associated with map reading are important influences on task performance.

10a TERRAIN VIEWED FROM THE AIR

Most maps give a plan view of the terrain, using projections which minimise sources of absolute and relative discrepancies between the contents of the map and the terrain of which it is an image. This facilitates the determination of range and bearing information but it rarely corresponds to the spatial arrangement of terrain features viewed from the air. The closest visual correspondence occurs when a small region of the earth's surface is viewed directly overhead from a great height. Many satellite photographs demonstrate this clearly when they include distinctive shapes such as coastlines or islands which are instantly familiar because they resemble so closely maps of them. In aviation such viewing conditions are so unusual that they can be discounted as influences on aviation map production. A vertical view may be necessary for some tasks, such as bomb-aiming, supply dropping and precision hover, but the design of most cockpits ensures that the terrain is usually viewed at an angle from the air.

Correlation of the map with the terrain may involve a mental rotation of the pattern of cartographic information or an orientation of the view of the terrain. Alternatively, the information may be encoded in verbal terms and on time-and-distance variables rather than simple visual pattern matching. Aircraft altitude, speed and associated visibility factors are important variables. From high altitudes, many terrain features cannot be seen because they are too small or contrast insufficiently with their backgrounds, while those which can be discerned may be obscured by prevalent haze in certain regions. At low levels, the angular subtense may be greater than the threshold for acuity, but there is often inadequate time to recognise and identify many features or to interpret their significance correctly. Factors affecting visual acuity, target detection and identification have been discussed in Chapter 3.

The effectiveness with which the aviation map may be related to terrain viewed from the air greatly depends on whether the map was compiled from information about the features likely to be visible from the air. An understanding of map usage and of the users' needs, and a map specification that meets the users' requirements, are essential if the aviation map is to be much more than a ground map with over-printed air information. In particular, the progressive replacement of ground survey techniques with aerial photography implies that certain categories of data, not hitherto surveyed but visually prominent from the air and potentially useful in air operations, can in principle be considered for inclusion on aviation maps. Such changes, if they are made, may be accompanied by the removal from air maps, or from certain specialised maps, of information categories which owe their presence to their importance on the ground rather than to their visibility or significance from the air.

Maps based on aerial photographs (orthophotomaps) have been produced for aviation purposes, such as the Pictomap series at 1:25,000 scale (Wickland[161]). These have advantages over conventional line maps in the case of updating and speed of production, and they are particularly useful for operations in remote regions where map coverage is poor. Evaluations have shown that on some tasks, orthophotomaps may produce comparable performance to conventional line maps, but often this is only achieved after considerable cartographic annotation of the photographic image (Berry and Horowitz[515]; Wheaton et al.[504]; Anon[665]; Hill[434]). Some of the additional information contained on photo-based maps, such as field and wood patterns may be useful for certain aviation tasks, such as low-level helicopter tactical operations. However, for many tasks, such as low altitude high speed aircraft navigation, detailed photographic information is often redundant and irrelevant, and only serves to clutter the map and reduce contrasts for other important features.

One approach to deciding which terrain features should be selected for inclusion on aviation maps is to start by measuring the angular subtense at the eye of the subjects on the ground corresponding to a variety of cartographic information categories, for several specified heights (Waters and Orlansky[24]). Angular subtense is only one of several factors determing the visibility from the air of features on the ground. Nomographic tables of the predicted visibility of various

kinds of features may be compiled using pilots' reports of what can be seen from the air in conjunction with more theoretical criteria of visibility (Waters[332]). The resulting classifications of predicted visibility may be combined with data on angular subtense to give guidelines of features which should be considered for inclusion on the map. When such proposals, or alternative ones, are formulated and used to produce experimental aviation maps, it is necessary to evaluate these under the envisaged operational conditions, such as high speed high level flight (Schreiber[25]). This will establish whether the most suitable terrain features have been chosen for depiction on the map, and confirm that the format for depicting them is satisfactory and operationally efficient. Such checks from the air were singled out by Wulfeck et al[101] as the most important recommendation for improving maps for high performance aircraft.

Navigation procedures which can be followed at high level by comparing the map with visible terrain may no longer be practical at low level, because of the changed environmental conditions. Mercier et al.[335] included noise, acceleration, vibration (see Chapter 5d), manoeuvres, kinetic heating, and insect and bird strikes in a discussion of the effects of the environment on vision at low altitudes. External visibility is affected by the structure of the aircraft, cabin conditioning, transparencies, atmospheric transmission, dazzle and ambient illumination (see Chapter 5c).

The visibility of an object depends on the angle it subtends at the eye, the contrast and pattern of the background, and the angular velocity of the feature. Dynamic visual actuity is poorer than static visual acuity; as angular velocity increases so the minimum subtended visual angle of a discernible feature increases and a "blur zone" is created when objects of a given size have an angular velocity in excess of about 100 degrees per second.

Features with vertical significance are more important at low altitudes than at high altitudes partly because of the increases in the visual angle subtended by objects at the eye, and partly because of improved contrasts for objects viewed against the horizon. The area of ground visible to the eye decreases as altitude decreases; it may become severely restricted at very low levels in undulating terrain because of obscuration. Flat features on the surface of the terrain such as roads, and railroads, may not be detected until the aircraft is almost directly overhead, and the time available for recognition and identification may be seriously curtailed unless the feature is anticipated and detected at the earliest possible opportunity. Often the most visible features are off-track, to the side of the aircraft. However, distances are difficult to estimate at low altitudes, and off-track features tend to be used only for general confirmation of positions, supplementing checkpoints that are directly overflown. Successful low level navigation may only be possible over terrain which has become familiar from studying maps of it beforehand (Wright and Pauley[349]).

The probability of detecting features may be assessed by separating various factors affecting the detection process, such as height, angular subtense, time available, and information obtainable in a glimpse, obtaining separate probabilities for each, and combining them (Linge[445]). For many factors, the assignment of detection probabilities is largely speculative, so that the combined assessment may not inspire great confidence. Empirical studies, such as that of McGrath and Borden[121] produce usable data for the area tested, but there are serious problems in generalising the results to other geographical regions. The requirements for maintaining orientation and for target detection may be so different that separate displays are needed for the two roles (Dure[377]). In practice, larger scale maps are used more for identifying targets, IPs and for line-search reconnaissance than for transitting en route. The specification of guidelines for choosing fixpoints to assist and confirm positions en route is a recurrent problem, particularly in view of the interactions between feature detection and navigational accuracy (Heap[124]). Some assistance may be afforded by suitable training and familiarisation with the principles of perspective geometry in relation to viewing terrain from an oblique angle (Larve et al.[451]). Flight data give some encouragement to theoretical studies of the visual factors which determine target conspicuity and which guide search patterns (Davies[666]). If the findings from such studies can validly be applied, it could be concluded from the work of Rappaport[667] that visual redundancy might aid recognition in noisy displays and that successful map-terrain correlation might be more probable with larger scale maps. Boynton and Bush[668] demonstrated that the manipulation in controlled experiments of basic psychophysical variables such as contrast, size, and distance may elucidate useful principles in defining the variables which are relevant to the performance of visual air reconnaissance.

The method of relief portrayal on the map is particularly critical when the map is correlated with terrain viewed obliquely from the air (cf Chapter 9a). Shaded relief has been widely used to create a three-dimensional impression, but variations in the application of hand drawn techniques and the unidirectional nature of the shading limit its usefulness. Profile drawings and oblique perspective three-dimensional graphics with vertical exaggeration give a vivid impression of terrain shape, and are easily correlated with the scene outside the cockpit when the view-point is the same. These may facilitate the identification of targets when the direction of approach to the position is known in advance. Research is needed to show how critical the correspondence of viewpoints is for matching performance. Automation in cartography has increased the practicability of perspective maps and they could readily be included as inserts on filmstrips for moving map displays for mission specific identification points and waypoints. Perspective views are almost certainly to be made available as options on computer generated, cathode ray tube map displays. It should be recognised though that in presenting an artificial, stylised view the critical aspects of terrain for navigation purposes must be identified before successful electronic simulations can be made (Gartner[669]). The images which were simulated had some affinities with those postulated by Gamezo and Rubakhin[628] as a result of their studies of how an aviation map is visualised in terms of terrain. Such images could be used to assist training by demonstrating when the image had been correctly formulated from the map, and by revealing the nature and causes of errors in image formation.

In spite of many problem analyses, laboratory studies, simulation exercises and flight trials, the difficulties associated with providing maps which complement terrain viewed from the air have not yet been satisfactorily overcome. There is a series of problems, the nature of which depends most on aircraft height, speed and operational role. For some roles, the ideal map may be unattainable, as for example for low level close support helicopter operations at night, where the constraints are so severe that no map may successfully resolve all navigational problems. In other circumstances, a satisfactory solution has proved elusive despite painstaking work, and a map series has proved disappointing in use, although recommended procedures appear to have been followed in its development and procurement.

Gaps remain in our knowledge of what information is needed on a map for a given purpose, and how it should be portrayed. The basic difficulty is still encountered, that many terrain features which are visible from the air do not appear on the map, and that many of the features on the map are not readily visible on the terrain from the air. Pattern distortion associated with angular viewing of the terrain cannot yet be allowed for satisfactorily on the map, and therefore the matching of map and terrain is rarely of similar patterns but of one pattern, the map, which shows the relative positions of features approximately as they are geographically, and another pattern, the terrain viewed from the air, which is subjected to gross and progressive distortions in one or both dimensions. Evidence on how to optimise the matching of such patterns, and how to compensate for pattern distortion by map specification and design, is sparse, to the extent that it is not known how far such an approach might prove to be feasible. Within the map there are difficulties of portrayal because the relative operational importance of cartographic information categories is a main determinant of the visual emphasis that is given on the map. Hence the patterns of information which are most readily discerned on the map, such as airfields, are those which are significant for critical tasks, but these patterns may be quite unrelated to their visual prominence on the terrain viewed from the air. Attempts may even have been made to camouflage on the ground the features of greatest operational significance such as pylons or military installations. The results in that the patterns which are most prominent on the terrain viewed from the air may correspond very little with the most prominent visual patterns on the map of that terrain. From such evidence, the conclusion seems unavoidable that further improvements could be made, if required, in designing maps suitable for use in conjunction with a view of the terrain from the air.

10b CONTINUOUSLY-GENERATED COLLATERAL DISPLAYS

Technological developments have produced a proliferation of sensors and displays which can be used to provide indirectly sensed, continuously-generated terrain information within the cockpit. All pose the problem of how maps can be used with them for maximum operational efficiency. All are far more inflexible than maps in the form in which they can present information to the user. Therefore, opportunities to adapt these new displays to make them more compatible with existing maps are limited. Most frequently it is the maps which have to be adapted to the displays. The main practical problems are therefore to define what information is needed on the map, and to consider how it should be portrayed to facilitate correlation with the sensor imagery. Processes of experimental evaluation and verification are also essential.

The display may be a low-light television picture, a radar display (processed to various degrees), a side-scan radar display or an infra-red line scan display. It may be presented on a cathode ray tube, or recorded on film or tape. It may be displayed and recorded, or merely recorded. It may look quite like the terrain, as in a TV picture of it, look very different from the terrain, as in an unprocessed radar display, or look superficially similar to the terrain but be different from it, as in an infra-red display.

Each display poses specific problems of interpretation for its users. With training and familiarity, the user learns what kinds of feature generally appear on the display under a variety of operational conditions, and the visual appearance which they typically have. He thus learns to interpret and use the display, and to select what is relevant for a given mission. It may take much longer to recognise what the main sources of error and misinterpretation of the display are. If the display proves to be inadequate for a mission, it may be difficult to determine why it has failed, or whether it could have been interpreted differently to give better prospects of success.

With every new display producing continuously-generated material in the cockpit, the same basic questions arise in relating it to aviation maps. These are:–

(1) Is there any role for a map in relation to it?
(2) If so, in what ways could cartographic data enhance the value of the display?
(3) What cartographic information should appear on a map intended for use in conjunction with the display?
(4) Is the map information needed at the same time as the new display; if so should it be separate or superimposed, and in what form is it required?
(5) Is it necessary, or feasible, to match automatically the terrain on the display with the map of the same terrain?
(6) Does any existing map contain the required cartographic information in a suitable format, or does the new display require new maps?
(7) Have the categories of cartographic information which the new display requires been surveyed, and can they all be portrayed on a map without ambiguity?
(8) How should the adequacy of the maps in relation to the new display be measured and evaluated?

Although it is a simple matter to pose such questions, satisfactory answers which could lead to an effective map specification can be elusive. There may be no definitive answer to the question about what information the map should contain, because no one is sure what will appear on the new display: what does appear may depend a great deal on highly specific circumstances, and general answers may not be forthcoming. Certain features may appear reliably, but be obscured in a dense clutter of other information which cannot be mapped. Some features may frequently be displayed, but their relative prominence, and therefore detectability, may be unpredictable. Map specifications must classify the information into different categories, but the display with which the map will be compared may not consistently accord visual prominence to any cartographic categories. Even radar displays of terrain are directional, whereas the map must be useable with radar displays no matter where the aircraft is in relation to the terrain.

Continuously-generated displays may be subject to the problems of dynamic visual acuity. The movement of moving map displays is within the limits for dynamic visual acuity (Carel et al.[196]) but large scale dynamic displays showing the terrain being flown over in high speed low level flight may have an angular velocity which prevents the discrimination of detail, and allows glimpses of features only if they are large, distinctive, and with good contrast. Ultimately, if the scale is large enough, the height low enough and the speed fast enough, the whole display becomes an unusable blur to the viewer. If such operational conditions are envisaged, it may be most important to portray on the map any large distinctively shaped features which may still be identified under the most adverse conditions.

Evidence on dynamic visual acuity obtained from laboratory settings may be expected to remain valid under operational conditions, unless there is an additional relevant variable present, such as vibration or turbulence, which has effects on dynamic visual acuity in its own right. Findings such as that of Lippert[670], that angular velocity giving zero legibility was about three times as great as that giving complete legibility, are likely to remain broadly true in other contexts with similar experimental material and viewing conditions. The figure of 8 degrees per second for the minimum angular velocity at which search performance for alphabetical targets began to show a decrement might also be a useful guide to expected results elsewhere with broadly similar material (Williams and Borow[671]). Their finding that displays to be searched should move horizontally rather than vertically for efficient search performance may be general, but could be an artefact of the experimental material, and is best treated as a hypothesis requiring verification in other contexts where it is a practical option. Such constraints represent fundamental limitations in the users of displays, which cannot be circumvented except by reducing the angular velocity. As long as the role of aircrew includes the integration and correlation of different sources of navigation information and the verification of system performance (Polhemus[672]), the limitations imposed by such constraints must be accepted.

Adapting maps to new types of display often leads to potential sources of error or inaccuracy which have to be circumvented. The corrections necessary in compiling roller maps for navigation displays were discussed by Abraham[673], and depend on factors such as scale and projection. In matching a continuously generated display with a topographical map used as a reference, estimates of magnitude and direction of any offsets have to be made if they are to be corrected, and Diamantides[674] suggested that the reference map could be designed to facilitate estimates of offset in cross correlation. Diamantides[675,676] pursued this idea by noting that if continuous tone was converted to black and white equivalents, pattern could be described in simple and quantitative terms. This description would in turn permit correlation of any pattern with any other pattern similarly derived, and offsets could be detected and correlated by pattern matching. More elaborate recent processes of digital scan conversion, applied for example to infra red line scan material (Berry[677]), allow this principle to be extended to the matching of more elaborate patterns if the operational gains warrant such effort and commitments.

One envisaged role of the moving map display was to enable the offsets associated with navigation errors in the automated systems in the aircraft to be detected and correlated by visual or radar fixes; it was also considered that the moving map display would help in interpreting other continuously generated displays within the cockpit (Roscoe[403]). The correspondence between the scale of the map and the sensor information, and the equivalence of the area displayed, may affect matching performance; Enoch[205] has shown that the size of the display affects the efficiency of eye movements during search. A possible source of ambiguity is whether such displays show north at the the top or direction of track at the top, and how this decision should affect the nature and orientation of reference map material. While it may be feasible and desirable to provide a facility to enable a moving map display to be updated from other sources of evidence (Lewis and Anderson[354]), the possibility then exists that the updating will be wrong from time to time. This raises the question whether any updating whatever should be accepted, or whether the automated navigation system could be used to define a region of plausibility of error, outside which proposed updatings would not be accepted by the system without some requirement to crosscheck, confirm, or obtain further data.

An implication of some map-matching studies was made explicit by Braid[344]. In emphasising the advantages of matching and of navigational accuracy which moving map displays combined with radar can bring, he pointed out that, for matching purposes, accurate updating may still be achieved when there are distortions and inaccuracies in the displays being matched. Various discrepancies and omissions of information can be tolerated in matching tasks without penalty, in ways which could not be tolerated if either display was being used by itself. The studies of Lichte[58] encountered the problem of classifying radar returns in terms of the extent to which they permitted positive identification of features, but matching renders this much less necessary for any one feature, and it may still be possible to match patterns without successfully identifying specific features in them. Since radar returns emphasise terrain, it would be expected that enhancement of hill shading on a map intended for radar-map matching would improve the interpretation of radar returns in hilly terrain at low level, (Barrett et al.[345]). Many of the changes designed to improve the map for radar

matching may have benefits in other contexts which also require reduced information density, the elimination of visual clutter, and changes in the emphasis of colour and contrast coding.

The work of McKechnie[218,437] demonstrated that increased information about targets provided in the form of map annotations is of great importance in identifying them on side-ways looking radar imagery and in reducing identification errors. He used a range of targets of significance for tactical operations. As more information was provided about the targets, more targets were correctly identified, and fewer errors were made. Results depended very little on aircraft speed, and apparently the choice of map was not critical either, as long as targets were circled on it. Since under certain experimental conditions very good performance was achieved, the selected targets must have been clearly discriminable, and performance might not be so impressive with other material. However, the studies provided a convincing demonstration of the vital role of maps in relation to continuously generated material, at least when targets can be designated beforehand. The availability of the map during or before the flight did not in itself aid the location of targets on side-scan radar imagery (Welch and McKechnie[436]), and it was target marking on the map which produced spectacular improvements in performance. However, it does not follow that briefing or previous familiarity with the map would never be worthwhile for interpreting side-ways looking radar, and McKechnie and Griffin[678] subsequently demonstrated that appropriate briefing material could compensate for high rates of image motion. The marking of a target on the map presupposes that it will be visible on a side-ways looking radar picture of the appropriate terrain. A similar problem was discussed by Leonardo[679] in relation to a continuous strip derived from radar by photographing a cathode ray tube. An attempt was made to specify similarities and dissimilarities between the radar map strip derived in this way and conventional photographs or maps, in the broader framework of evaluating the role of photographic and cartographic techniques in relation to a variety of alternative recording systems.

Image-intensification night vision goggles (NVGs) present an unusual problem in that the map that has to be compared with the terrain image may have to be viewed through the same sensor as the terrain. The monochromatic image and poor resolution of night vision goggles make map reading an almost impossible task with conventional maps, even when the goggles are focused down onto the map, and not onto the instruments for the lower half and at infinity for the upper half, where bifocal goggles would normally be focused. Special purpose, black on white, maps need to be designed for use with NVGs to overcome the resolution problem, and even then it is uncertain that these would be acceptable when the operator has the option of taking off the goggles to look at the map or relying on a second crew member to do the map reading (Barnard[406]).

One fundamental problem is that it is not valid to presume that a cartographic category or a particular kind of feature will be reliably visible on one kind of material, just because it has been on other kinds. Because of this, it is necessary to start without preconceptions in evaluating the information which appears on a technologically new display. Earlier studies on different kinds of material may provide useful classifications of features which may be followed, and may be helpful in indicating the tasks and experimental methods which have been most successful for evaluations in the past, but they cannot provide evidence about specific features and categories which can be taken on trust without verification if different sensors are used. Thus, with a new display such as digitised infra-red linescan, the nature of the sensor can be used to predict the kinds of feature which would be highly visible (such as metallic surfaces) and the kinds of conditions which might impair the visibility of features (such as weather, ambient temperature and time of day) but hypotheses so derived still must be verified with suitable experimental material.

10c PHOTOGRAPHIC MATERIAL

Photographic collateral material has three distinct roles in relation to aviation maps. Firstly it may be used as a source of up-to-date and detailed information to aid map compilation and production. This vital role, discussed elsewhere, is not recapitulated here, except to note that this requirement may determine the nature of the photographic material available for other purposes. Secondly, photographs may be used in conjunction with maps in order to plan, execute or evaluate a mission. Here the map and the photographic material are physically separate, and each is used in various ways to assist in the interpretation of the other. Thirdly, photographic material may form the primary display, on which cartographic annotations are superimposed to add information or to change the visual emphasis.

The value of air photographs as an aid to map interpretation, and the value of maps as an aid to interpreting air photograhs, have long been accepted for military purposes (Lobeck and Tellington[15]); each can be an invaluable source of complementary information to the other (Dickinson[134]). Sometimes the use of air photographs is a necessity because, for many regions of the world, mapping is still inadequate, and the availability of suitable air photographs determines the content of the maps which do exist, there being no alternative source of reliable and detailed information. For many regions too, the photographic information is much more complete and detailed than that on any map, but this does not imply that all the detail on the photograph can readily be interpreted or that all the information needed for mapping is present on the photograph in a form which can be understood. Hence, the interpretation of air photographs is recognised as a skill requiring knowledge and experience. Some information, taken for granted on topographical maps, may not be present on corresponding air photographs: undulations of terrain and continuous gentle slopes may not appear on photographs taken vertically, and certain vertical features on the ground may be unrecognisable. The most prominent features in an air photograph do not necessarily have most operational significance, and visual balance is not controllable in a photograph to the large extent that it is on a map. Air photographs

are taken for many purposes, not all of which have any relevance to maps (St. Joseph[135]).

Many ways of using air photographs with maps have been considered or tried. Bishop et al.[126], *in their study of* mapping for helicopters, suggested that the map should be scrutinised as the sole navigation aid, and recommended that its use jointly with air photographs should be explored. For a radar bombing task, Daniel et al.[55] devised and tested a procedure in which photographs taken along the bombing run were matched with maps, and they showed that bombing errors were mainly caused by perceptual factors. Map matching provided an effective means of tackling the problem, and could serve also as a training aid. Lichte et al.[58] demonstrated that prior familiarity with an appropriate map enhanced the ability to locate targets subsequently on photographs, although they advocated bold symbols for relevant cultural features on the map. Berry and Horowitz[515] set out to demonstrate that for some Army Aviation purposes air photographs may be as good as, or better than, maps. They concluded that people with no relevant training could interpret air photographs more efficiently than maps, and they suggested that topographical symbols should in general be more pictorial, to improve their interpretation. As might be expected, they found that terrain height was more easily determined from oblique than from vertical air photographs.

The use of air photographs has generated studies on how they should be interpreted, and on the processes involved in doing so, which Hempenius et al.[680] had difficulty in defining. The model which they proposed included the effects of methods of observation, of expectations, of confirmation techniques, and of discarding hypotheses. An alternative approach was adopted by Sadacca and Schwartz[215] who applied Torgeson's[681] multidimensional scaling techniques for identifying factor loadings to assessments of photographs in terms of their potential usefulness as sources of intelligence information, the intention being to improve the performance of image interpreters by developing scales of image quality. It was found that image quality was assessed by photographic scale, sharpness, contrast and content. Image interpreters also participated in an experiment in which designated targets on photographs had to be located on maps in paper or projected form (Laymon[305]). The former was preferred, but the finding was influenced by an experimental artefact; if the photographed region overlapped two maps, the maps were combined in paper form but had to be viewed sequentially in projected form, which led to longer viewing times. A further variable was that the photograph was fixed or could be oriented in relation to the map, but this variable did not affect the ability to find on the map the designated feature on the photograph.

Most studies on the detection of targets have examined psychophysical attributes of the target, and many of these attributes have some apparent relevance to target detection (Kause[137]). But the probability that a target will be detected depends also on characteristics of the detector. Thornton et al.[258] established that the ability to identify targets in air photographs depends to some extent on perceptual style. This concept is derived from Witkin et al.[682] and refers to the fact that the ability to extract a visual item from an embedded context is associated with field independency and is a relatively stable individual characteristic, while still permitting some improvement with training. Attempts to predict target detection performance by classifying characteristics of the target and of its background continue to be made (Zaitzeff[683]) and can successfully account for most of the variance by considering many factors, some of which are highly correlated. There is always the problem of defining and weighing all the factors in predicting the detection probability of a given specific target of operational significance, where prediction becomes complicated and often not sufficiently accurate to justify all the effort involved in making the prediction. Since so many psychophysical and individual factors have been shown to be relevant, accurate prediction of detection performance of a specific target, as distinct from a group or class of targets, may continue to be uncertain.

The variety of image producing sensors which may be avilable in flight, and the quantity of displayed data which they generate, lead to difficulties in analysing and evaluating so much information, and to a search for quicker and cheaper means of extracting the information needed. In this context, Olsson[684] explored the application of spatial sampling techniques to identify and measure geographical features on air photographs and maps. The technique seems to have some limited applications. Some modern displays generate problems by preventing the use of traditional aids. The commonest of these is probably annotation, where the conventional paper map has the advantage over more sophisticated displays of cartographic information. A criticism of projected map displays has been that they cannot be annotated, but Fromm and Gray[685] showed that in principle this might be possible photographically by coating the film, a somewhat unconventional use of photographic processes with aviation maps. The annotated layer could be dissolved and replaced without damaging the map.

In designing maps, there is by now a wealth of experience which can be used to help decisions on content and portrayal, but if the air photograph is the primary display, the main relevant research has been on pattern perception and interpretation, rather than on how to use it as a map and how to annotate it. It may be possible to use air photographs, or derivatives from them, for navigational tasks which have hitherto required maps, but the performance levels which could be achieved with photographs are uncertain, and the best ways of adapting them for new roles are as yet undiscovered. A variety of image-based maps, such as orthophotomaps, can be specified; initial studies sought to compare them with conventional maps, partly to see if they deserved serious research, (Hill[164]). When it had been shown that, though generally inferior to standard line maps, they could be useful, the next step was to produce orthophotomaps in alternative ways, varying their general appearance and amount of cartographic annotation, to find out what the optimum format of orthophotomaps might be, and whether changes in their appearance affected performance with them. It did not, although the task used was a laboratory one with limited field application (Hill[309]). Tasks were then expanded, together with physical viewing conditions such as lighting, and field tests as well as laboratory tests were used (Hill[516]).

Differences in performance were generally small, but tended to favour the standard map over the orthophotomap, as did the more limited studies of Smith[165] on point symbol readability on an orthophotomap.

Some of the problems of image based maps, which Johnson[404] suggested should be the subject of research, have still to be resolved. These include the basic ones of how to optimise the map, when to use it, how to annotate it, and how to compensate for such deficiencies as comparatively poor relief representation without taking away any of its potential advantages, which are themselves only vaguely defined. These begin with the initial impression that an air photograph looks more like the view of the terrain from the air than a map does. Features on the ground therefore appear on the photograph as they look from the air, and do not have to be represented by a symbology which may not even be meaningful or pictorial. It is conceded that some features of operational importance may be visible on an air photograph, may lack visual prominence commensurate with their importance, or may look unfamiliar and remain unrecognised, particularly if they are vertical. Furthermore, the air photograph shares with many other images sensed from the air the problem that much of the information on it is visual clutter. This is of no use for any operational purpose, and often constitutes a source of performance degradation, because it obscures, changes the appearance of, or affects the visual prominence of what is important. Yet the idea persists that these difficulties could be overcome because annotation can ensure that what is most important is present and receives suitable visual emphasis. Often in principle it can, particularly for regions already well mapped; but annotation progressively alters the visual balance and undermines the claimed benefit of a close correspondence between the air photograph and the ground. An implication of annotation is that it can be added without obscuring other important information already present on the photograph. Annotation must also rely on information from another source for the accurate addition of information which is not present at all on the photograph. A road may be present but invisible on the air photograph for example, because of trees. If it is added when it cannot be seen, this may initiate a fruitless search for a feature which apparently is not there. If the mapping for a region is poor, there may be evidence of the approximate position of a road, but not enough to annotate it on a photograph which does not show it.

There remains the recalcitrant problem of terrain. It seems to be assumed that it is operationally essential to find an acceptable way of emphasising terrain by annotating air photographs in an appropriate fashion. It is debatable whether a suitable convention exists which would allow this to be done to acceptable operational and perceptual standards without obscuring other information of importance on the photograph, or other annotations, and without adding more clutter to the excessive clutter already present. The successful integration of air photographs and cartographic information has not yet been achieved in any way which could not be improved upon.

10d JOB AIDS

The concept of job aids covers all items within a working environment which are ancilliary to the basic functions and equipment. Often job aids are portable, and some have temporary or transient relevance. They may assist the actual performance of the task, or the choice of procedures and the fluency with which they are followed. From the point of view of flying an aircraft, aviation maps may themselves be construed as job aids, since the maps are not an intrinsic part of the activity involved in controlling the aircraft, but contribute to its correct navigation and do so more efficiently if the most appropriate maps have been chosen for the mission. However, in the narrower context of this volume, where successful map reading is taken to be the primary task, job aids refer to the manuals, instructions, procedures, tools, and items of equipment which facilitate the map reading process or make it more efficient.

Job aids usually apply to the performance of tasks under operational conditions, but they may also refer to training methods and they should normally be a feature of the total design. The map design should therefore have been influenced by the job aids with which the map would normally be used. The aids should have been designed and selected to complement and be appropriate for the aviation maps, to facilitate the performance of certain tasks. A good job aid should have specific and clearly defined functions, so that there is no ambiguity about the circumstances when its use would be appropriate. Accordingly, it should have been designed from the outset to be suitable for use in a known manner with a particular map under specified circumstances.

An early attempt to design a job aid was described by Cramer et al.[330]. Firstly, they identified the purpose of the aid, in that it would provide essential information to meet a particular requirement not already being met adequately. The aid was intended to provide, for single seat aircraft on routine cross country missions, a collated listing of relevant navigational data assembled from many sources into a single display. Secondly, the kind of aid needed was defined as one which collected the data into a standard format, showing interrelationships and sequences. Thirdly, a more detailed analysis suggested that a tabular format would be appropriate, and its detailed content and layout were recommended after full consultations with its potential users. The aid was then made. The fourth stage was to evaluate it (Cramer et al.[401]), in order to demonstrate that it was better than any available alternative, and, if necessary, to improve it further. The above stages are the normal ones in developing and testing a job aid.

Certain job aids are intended for use directly with the map itself, and may also be treated as tools. Examples are proportional dividers and the opisometer (Monkhouse and Wilkinson[139]) which may have distinct but related functions in map production and in map usage, and, strictly speaking, are job aids only in the latter role. A variety of aids are devised to permit tasks to be done with the map which could not otherwise be done so well. An example was Snell's[686] proposed aid to analyse the line of sight between any two designated points on a map, without recourse to drawing

earth profiles. Another example was a job aid in the form of predrawn reference angles on cards or on maps which, it was hoped (erroneously), would improve the ability to estimate angles of drift directly from maps (Waller and Wright[350]). An example of a different kind of job aid was the attempt by Fromm and Gray[685] to devise a means of annotating projected moving map displays, thus enabling the transparencies to be re-used. Even such a simple process as circling targets on a map to facilitate their location on a sideways looking radar display may prove to be an effective job aid (McKechnie[218]). Alternative ways of presenting briefing material may prove to be equally effective as job aids, once the value of briefing material as a job aid has been established (McKechnie and Griffin[608]).

Other job aids may be related primarily to a particular function. Nelson et al.[216] discussed the reference materials (job aids) required for an image interpretation task. They were concerned with the roles of such aids, rather than with the detailed design of each. Broad views of job aids were adopted by Watkins[383] and by Adderley[384]. The former was particularly concerned to trace the origins of the format and content of various job aids for the pilot, and the extent to which they were influenced by international standards. The latter made an attempt to define how aircrew documentation might be improved. Documentation includes various manuals, logs, briefing data, orders, notices, maps and charts. Some are specific to the aircraft, some to the crew, and some to the mission, its objectives and the prevailing conditions. As job aids, many could be improved to meet the pilot's requirements more adequately and quickly, and to permit the relevant information they contain to be found more readily when it is needed.

The specification, design and evaluation of job aids are a subject for study in their own right. In general, the standard human factors principles for the design of displays and controls, summarised in human factors handbooks, can be applied to job aids, with due allowance for any particular environmental factors such as vibration or red ambient lighting. Job aids can be analysed also by standard techniques such as checklists (Easterby[96]).

The normal practice in considering job aids for tasks using aviation maps is to design and adapt the job aid to fit the map, but not to allow the map design to be much influenced by the requirements of job aids with which the map will be used. In general, this approach represents the correct emphasis, but may take it too far. Aviation maps have to be used in conjunction with various job aids in the form of manuals and other documentation. These should be designed so that it is apparent from their format, layout, construction or coding which maps they pertain to. But if a map is intended to be used frequently in conjunction with certain documentation, it is advantageous to use aspects of the map design to facilitate cross-referencing to this material, if this can be done without any impairment of the efficiency or utility of the map in its operational roles. Various methods which might help to achieve this aim can be formulated. They include tags, marginal annotations, and notes incorporated in the legend. A further practical method is to ensure that the physical aspects of the map – sheet size, sheet divisions, methods of folding, methods of cross-reference to adjacent sheets, and so on – follow the same classifications as those for other aids and documentation, so that knowledge of one can be used together with a simple coding cross-reference system to provide quick and reliable knowledge of the other. It would also be an asset if the map contained more information, even if only as footnotes to the legend, on available job aids with which the map had been designed to be compatible.

An aviation map takes a long time to make, is relatively infrequently revised, can portray only a small and selective portion of terrain features, is only one of many aids to aerial navigation, and contains a great deal of information which cannot be fully and accurately measured and interpreted without some form of assistance: therefore there are many job aids which may complement or supplement it. These may give more specific information which is needed for a particular mission, more up-to-date information, or inform the aircrew about relevant factors which would not normally be mapped at all. They may permit the map usage to be extended – by accurate route plotting, distance measurement, heading derivation, and deduced timings. They may permit information to be added to the map, by annotation, overlays or other superimposed material. They may extend the display techniques for presenting the map, or the circumstances under which it can be used. They may add to the range of tasks for which the information on the map is relevant, where the limitation has been imposed not by the map content itself but by the inability of the user to perform certain functions with it or to make certain extrapolations from it. Appropriate job aids in the form of various tools or equipment items may extend the man's capabilities and hence those of the map.

The multiplicity of job aids which may be used with aviation maps prevents a detailed examination of each in the present context, but in any event, such detail would tend to be superfluous. The basic principles are to identify functions for which job aids could be appropriate, define the nature of the required job aid, specify its details in terms of such factors as the speed, precision and accuracy to be attained in use, construct it according to sound ergonomic design principles, evaluate it, and if necessary modify it until its envisaged aims are satisfied. In this process, characteristics of the tasks, of the users, and of the environment must influence the design. In particular, a job aid is, *a priori*, not intended to be used in isolation, and therefore should never be designed as if it were. Its design must be compatible with the design of what it is aiding, facilitating cross-referencing, precluding ambiguities, and encouraging efficiency in use. The circumstances when it is needed should always be obvious, and its design should help to make these apparent. However, cross-referencing, aiding, and providing complementary or supplementary information are two-way processes. Therefore, while the primary aim must be to design an aid to relate to the map, it is also reasonable to expect that, at the very least, the design of the map does not hinder the provision of effective job aids for use with it, and preferably includes some positive design features to enhance the effectiveness of associated job aids.

10e VERBAL INFORMATION

An aviation map is a visual information display. Anomalously, the specification for producing it is initially expressed in verbal and not visual terms. The functions which it is intended to fulfil are stated verbally. Verbal instructions describe how it should be used. Missions, routes, targets and destinations are expressed in words. Reports depending on the map information are spoken or written. Map users in different places who need to liaise or confer must use words to convey to each other their intentions referring to map information. Words are used in briefings and debriefings, and to relate maps to various kinds of collateral material. The map legend provides a code to convert visual features into verbal concepts, and the meaning of the map content is ultimately verbal in the sense that it depends on the interpretation which the user puts upon the names for categories and sub-categories of cartographic information. The practical implications of this intimate link between the aviation map and verbal information have been strangely neglected, and with few exceptions (Taylor and Hopkin[151]) the consequences for operational efficiency have not been pursued or subjected to research. Some of the more abstruse aspects of communication theory and language have demonstrated the impossibility of conveying in verbal terms the intricacy and complexity of many cartographic interactions and relationships, and have thus focused attention on the map as a visual communication medium which cannot be fully and intelligibly described solely in words.

Cartography, whether construed as a science, a technology, or an art, has its own technical language. Often this relates the manipulation of variables within cartographic printing technology to their visual consequences on the map. The subcategories of a cartographic feature are distinguished by characteristics of their visual appearance on the ground, rather than by their functions or by their appearance from the air. This technical language remains unknown to most map users, and if it is known to them it is not much used; the distinctions it makes may have little operational consequence. Therefore the language used to define much of the map content and particularly the details of its physical appearance is not used thereafter to say what is on the map. As far as the user is concerned, there is often no direct verbal equivalent for many of the visual distinctions which the cartographer has been at pains to make, or for the means he has used to achieve them. The technical language of cartography, as expressed for example in the contents' pages or indexes of texts on cartography such as those of Monkhouse and Wilkinson[139] or Keates[120], is not the language of the user; it refers to the technical methods of portrayal and to the map itself, but not to the terrain which the map purports to be representing. The user's language with reference to maps is not that of the terrain features it portrays. In describing relationships on the map, the user relies on the language and concepts appropriate for describing the corresponding relationships within the terrain depicted on the map. Thus, the user's language may not be the most efficient *verbal* means of describing what is on the map or of referring to map content.

In the first paragraph of this section, various ways were suggested in which verbal concepts interact with the aviation map. Not all of these ways employ the same verbal concepts, since some relate to the cartographer, some to the map user, and some to the operational planner. Maps are not designed primarily to facilitate the verbal communication of their content. For many operational missions, the value of the map depends not so much on what the user sees on it as how well he can verbalise what he sees. To specify the meaning of a symbol on the map, the map reader uses words. Much effort has been expended towards making the portrayal of map features clear, and visually prominent if they convey operationally significant information. Efficiency and clarity of portrayal may be the cartographer's main intentions but do not suffice to ensure that the map meets the user's needs. For it to do so, the user must know the meaning of the portrayed symbology. A symbol on the map may be visually prominent and attract the user's attention, and it may convey information of great operational utility, but all this is of no avail if the user does not know what the symbol means. In practice, this generally implies that the user has to be able to specify verbally the feature which the symbol represents, and to understand the symbol in terms of a terrain feature.

It is possible for the user to make deductions if he does not know what a symbol means and has no legend to refer to. Two main kinds of deduction are possible. One refers to the nature of the symbol itself and the extent to which it is intended to be pictorial. Pickaxes may denote a mine, or an aircraft shape an airfield. The second refers to the context of the symbol on the map. A particular symbol which regularly occurs on a thick black line within or near numerous other symbols and patches of a distinctive colour, and never occurs anywhere else on the map, may be deduced as a railway station if the user knows that a thick black line represents a railway, the numerous other symbols denote man-made features and the colour patches are town fill. This deduction may be made, even though the symbol has no physical resemblance whatsoever to a railway station. However, any procedure which requires deductions of the meaning of symbols is bound to lead to mistakes from time to time, particularly when some symbols on the map do not represent physical features on the ground visible from the air. It is difficult to make pictorial symbols unambiguous for all users under all circumstances. In many contexts, an unknown symbol could plausibly represent a number of different features.

In practice, the map reader can only use those symbols the meaning of which he knows. In talking to others about the map content, he can refer only to what he can verbalise and understand, which may be much less than what he sees. He may not comprehend messages he receives if they refer to features on the map which are meaningless to him or have no verbal counterpart. Much of the detail on the map which the cartographer has assembled and portrayed with such care may seldom be referred to. The significance of much subtle subcategorisation, relying on relatively small changes in symbology, may fail to be appreciated by the user. It may be comparatively rare to find a regular user of aviation maps who is totally unfamiliar with a major legend category or a major set of symbols – although not so rare as is often

supposed. But it is comparatively common to find that distinctions between subcategories are ignored, so that adjacent examples of a feature, which have been carefully portrayed with different subcategories of symbology as an aid to discriminating between them, become confused because the users failed to recognise or could not verbalise what the subcategorisation was intended to convey. For example, if hachures have been employed to classify degrees of slope, much of the resulting information may be readily visible to the user, but if the relevant distinctions cannot be verbalised or are not understood they cannot be used by the map reader and he cannot convey their meaning to anyone else.

Having identified the problem of the relationship of verbal information to maps, the next step is to contemplate possible solutions. One must be to try and narrow the gulf between the cartographer's and user's terminology and concepts. It would be helpful if each understood more about the other's tasks and difficulties. More adequate instruction is needed to enable users to understand the map better than they generally do. An approach to map design would be helpful which ensured that all discriminations in symbology have a clear and unambigious verbal label and that they correspond with verbal concepts of the user rather than with technical concepts of the cartographer. Difficulties are bound to arise if a distinction has been agreed in cartographic terms but there is disagreement on how to describe it in words. Verbal labels should preferably have some correspondence with operational concepts and mission descriptions; otherwise missions are described in yet another set of terms, which appear neither on the map nor on the legend. Categories and subcategories of map symbology should be described verbally in terms which follow a common logic with the symbols, so that, given part of the set of symbols in a category and knowing its logic, it should be possible to deduce for the others both the nature of the symbols and their verbal designations. There is also a specific need in aviation maps to abandon verbal terminology which has become inappropriate because it relates to ground features which are seldom visible from the air and operationally insignificant.

Both the subcategorisation of symbols and their verbal labelling may have to be revised to take cognizance of what is important on aviation maps. Verbal messages need to be succinct as well as unambiguous: this implies discarding unnecessarily cumbersome verbal labelling while preserving useful visual distinctions. Features on the ground which are prominent when viewed from the air, and which are operationally important as waypoints, navigation fixes or potential targets, may require, for aviation map purposes, a brief distinctive verbal label even if their importance on the ground is so much less that they are not accorded a distinctive label there. To put this point another way, categories and subcategories of symbology on aviation maps reflect group usage, as do the words used to denote them. For aviation maps, some subcategories may be so operationally significant that they should be treated as categories in their own right, both in method of depiction on the map and in the words chosen to denote them. Other categories may be so unimportant on aviation maps that, both visually and verbally, they should be treated as subcategories only. In designing maps for aviation use, it is essential not to choose symbols and then look for suitable labels for them, but to choose only those symbols for which there is an appropriate unambiguous verbal label, and to eschew symbols which may be pictorially vivid but verbally vague. As with other visual information displays, so with maps: it is not enough to provide information on air maps in a form in which it could be used, but necessary to ensure that the map reader can actually use and understand it – and that includes expressing it verbally.

CHAPTER 11

CARTOGRAPHIC IMPLICATIONS OF TECHNICAL DEVELOPMENTS

Technical developments in aviation often pose new navigation problems that require some adaptation of existing cartography to take full advantage of the improved technology. Historically, cartographic support lags behing aviation technology. As discussed in Chapter 4c, there has been considerable delay in meeting the cartographic requirements for moving map displays (MMDs). Most operational MMDs continue to use standard mapping designed for hand-held applications (Taylor[642]). More recently, image intensification passive night vision goggles (PNGs) have gone into service in tactical helicopters to extend night capability. The requirements for PNG legible maps are still being researched and in the meantime aircrew have had to adapt their navigation techniques around conventional cartography (Barnard et al.[129]).

There are a number of reasons why delays in the cartographic response to new requirements continue to occur. The protracted time and high costs entailed in producing new map series and revising old specifications are major factors. Another reason is that the requirements for cartographic information are often ill-defined or simply not known during the development of new systems. Most cartographic agencies are production orientated and have limited effort to devote to research on new products for systems not yet in service. Organisations involved in the development and production of navigation systems rarely have access to cartographic facilities. Consequently, most new systems try to use existing maps whenever possible; changes to the content and coding of the maps, if they occur, usually follow criticisms by users after the equipment is in service. One possible solution to this general problem is to involve cartographers in the system design. Another is to establish a permanent cartographic research and development cell, independent of the producing agencies, with access to human factors expertise. The US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, though probably the closest approximation to this role, have no permanent human factors staff (Kothe[687]).

11a ADVANCES IN NAVIGATION

In the last decade, significant advances in positioning and navigation techniques have permitted great improvements in the ability to guide and control any aircraft, weapon or reconnaissance system. Applications of the major recent advances in navigation to guidance and control have been described recently (AGARD[688]).

As foreseen by Steakley[373], technological advances in positioning sensors have been characterised by improved resolution and reliability. Improved ECM protection and simpler operation may be added to this list. Precision navigation in the 1950s and 1960s normally had to be derived from a variety of sensors with the human navigator deciding the weighting of various sensor outputs. Now inertial navigation systems (INSs) with a performance of 1 nautical mile/hour CEP are commonplace with the advantage of compactness, security and independence of ground aids (McKinlay[689]). Higher performance, low cost, 'strap-down' INSs under development based on the Laser Gyro and Magnetic Resonance Gyro should provide sufficient accuracy for nearly all mission requirements without the present need for regular updating by visual or radar fixes (Matthews and Bates[690]). McKinlay[689] considers that it is not unreasonable to expect that an INS will give accuracies of 100 metres or better on missions in which the flight to the target is between 30 minutes and 1 hour. The wide variety of applications of the present INS potential includes sea-bed survey (Brown and Tait[691]), accurate blind weapon delivery and improved landing capability for civil aircraft.

Improved INS performance will reduce the necessity for regular monitoring and updating of system accuracy, ultimately eliminating the need for visual or radar updating altogether. At present, moving map displays (MMDs) driven from an INS, indicate inaccuracies and facilitate updating by visual reference to the ground. In the future, the other important advantages of MMDs, namely improved interpretability of navigation data, increased tactical flexibility, and the ability to monitor the achievement of the desired flight plan, seem likely to ensure their continuance as an essential system component (Taylor[338]).

McKinlay[689] focussed on the importance of accurate flight planning for optimum INS utilisation. He pointed out that it is pointless to strive for INS accuracies that are greater than the accuracies of the co-ordinates for IPs and targets that are the basis of the flight plan. A 1 mm error in plotting co-ordinates from a 1:50,000 scale map represents 50 metres error on the ground; to this must be added the inherent inaccurancies in the map due to survey, production and representational limitations. Sources of more accurate positional information than maps, such as satellite survey and NAVSTAR GPS, may need to be consulted for optimum INS utilisation. Maps should continue to be necessary for selecting routes and turning points according to the prevailing terrain and tactical situation. Automation of position plotting, flight plan storage, INS data entry, and flight plan display by methods such as the Ferranti Autoplan System,

Portable Data Store (PODS) and Combined Map and Electronic Display (COMED) (Bruce[385]; McKinlay[692]; Aspin[386]) seem likely to lead to improved INS utilisation.

Improvements in radar and radio navigation systems include UHF DF multiple angulation (Ernst[693]), ground-based angle measurement technology for en-route navigation (Blaschke and Peuker[694]), TACAN one-way ranging (Bohm[695]), enhanced ECM resistance by spread-spectrum communication (Sepp[696]) and new Microwave Landing Systems (Becker[697]). Some of these developments may ultimately lead to changes to the content and symbology on charts for radio navigation, terminal areas, approach and landing.

A major new development, called the NAVSTAR Global Positioning System (GPS), will provide a continuous satellite-based navigation system for the mid-1980s, applicable to military and civilian land, sea and air operations (Parkinson[698]; Gould[699]). The accuracy obtained by the system will depend on the complexity of the equipment on the aircraft, but it is claimed that on 90% of occasions a military user of GPS should be able to determine his horizontal position to better than 25 feet and his height to within 35 feet. Three dimensional velocity information is expected to be accurate to about ½ foot per second. This accuracy will not degrade with time and includes the effects of position, weather and time of day. Such accuracy means that GPS-equipped aircraft will have little use for ground-based navigation aids or airborne mapping-radars. GPS will probably be combined with an inertial system in military aircraft, giving a reversionary navigational capability. The cartographic implications of GPS are that it will almost certainly bring about the adoption of a new, global co-ordinate grid based on the position of the master control station (Gould[700]). All land, sea and air forces will be able to navigate by a common method within a common reference system. Surveys based on GPS will improve the accuracy of cartography to the benefit of precision navigation. Topography mapped in GPS co-ordinates could be used in conjunction with stored values of terrain height for the control of cruise missiles, for aircraft terrain avoidance and for weapon aiming. Also under development are the Position Location Reporting System (PLRS) for battlefield tactical location in helicopters with a potential accuracy of 10-30 metres (Bond and Lioy[701]), and the Joint Tactical Information Distribution System (JTIDS), a Communication Navigation Identification system for ground-based, airborne and seaborne communications, command and control (Brentnall[702]).

Ultimately, improvements in the resolution and reliability of automatic navigation systems should lead to perfect error free performance capable of meeting the most exacting mission requirements. Map reading in the cockpit is likely to be an increasingly redundant activity in aircraft fitted with advanced systems. Nevertheless, it seems likely that as long as there is a man in the system with an executive decision-making integrity monitoring role, there will continue to be a need for a map/map-based check system to facilitate monitoring and to provide an alternative in case of system failure. It seems unlikely that map reading will be entirely displaced as a simple, low cost method of aircraft navigation. Even the most proficient aircrew like to know where they are and where they are going, within a readily understandable reference system. Maps and moving map displays are the best means to achieve this and bolster the pilot's confidence. Like orienteering, aircraft navigation by map reading is a challenging task and it could continue as a leisure-time activity after it has ceased to be necessary for military and commercial aviation.

11b ADVANCES IN TARGET DETECTION, WEAPON AIMING AND GROUND MAPPING SENSORS

Some of the problems of air to ground visual target acquisition are reported in AGARD Conference Proceedings CP-100 (AGARD[703]). Briefing and target study with reference to oblique photographs, maps and perspective representations drawn from maps increase the probability of visual target acquisition (Parkes[438]). Unaided visual acquisition is difficult at the high speeds (500 knots +) flown in advanced low level strike aircraft guided by terrain following radar, radar altimetry and inertial navigation systems. Guidance and control implications of terrain following concepts are reported in AGARD Conference Proceedings CP-240 (AGARD[704]).

Recognition of identification points and targets, target acquisition and precision weapon delivery can be achieved in high performance aircraft with the aid of HUD optical sights, magnified narrow field-of-view television, radar and radar cursors, and laser range and laser designator sensor cued to the target by INS computed positions (Manville[705]; Marini and Hilgendorf[706]; Pickel[707]; Stahlie[708]). GPS equipment could also be used for weapon aiming; it has been claimed that a pre-surveyed target could be more accurately acquired by GPS than by radar in instrument meteorological conditions (IMS), and that such a system would also be more accurate than visual acquisition in visual meteorological conditions (VMC). Electro-optical acquisition systems, the most accurate available today, could also be improved in a GPS-equipped aircraft (Gould[700]). Despite these technological developments visual target acquisition, like en route map reading, seems likely to be sufficiently accurate as a reversionary mode and for checking system performance to require continued cartographic support in the foreseeable future.

Advances in the resolution, range and field of view of ground mapping sensors have implications for navigation, target detection, weapon aiming, reconnaissance and night, all-weather operability. Image forming sources and sensors available for modern aircraft include forward looking radar, TV, Low Light TV, Laser/TV, forward looking infra red, radar line scan, optical line scan, infra red line scan, and warning receivers. As discussed in Section 10b each sensor poses specific problems of display, interpretation and map correlation. The correlation of sensory imagery and maps can be facilitated by driving a moving map display from INS data. Superimposition or side-by-side comparisons of sensor imagery with MMDs can then be used to check the integrity of the navigation system and to update its accuracy. During reconnaissance, real-time or near real-time analysis of imagery may be possible with the aid of INS driven map displays.

Auto-correlation of maps or radar prediction with sensor imagery by computer pattern recognition is an attractive possible development, particularly for single-seat aircraft but this seems likely to be superseded by improvements in INS performance and by the simpler auto-correlation of digitised terrain deviation with radar altimetry. Conventional maps may not give the optimum pattern information for auto-correlation. Maps may need to be modified in content and coding, converted to digital form, or replaced by digitised satellite imagery in order best to facilitate computer matching. The feasibility of detecting changes in reconnaissance imagery, such as vehicle movements by computer matching should also be considered.

A major application of low light television and image intensification, passive night vision goggles (PNG) has been to extend helicopter night capabilities. These goggles affect the requirements for cartographic support of these operations (Hand[709]; Stich and Helm[710]). As discussed earlier (Chapter 10b) maps have been developed for helicopter night operations but evaluations have so far produced mixed results, (Johnson[404]; Whitworth[405]; Barnard[406]). Again, there is no inherent reason why acceptable cartography cannot be provided; the problem lies in the inadequate definition of the cartographic requirement.

Advances in remote sensing with multi-band photography, infra-red and multi spectral sensing have led to the extensive use of false-colour techniques for imagery analysis (Holter[711]; Anson[712]). Here, different colours are assigned to various radiation levels to emphasise and enhance particular distributions and to facilitate the detection and recognition of patterns and of correlations between ground phenomena. The resulting coloured imagery may be displayed on hard-copy colour prints or colour film, or on colour CRTs. These are essentually flexible colour coded displays and consideration should be given to the feasibility of studying the human factors optimisation of colour and developing where possible standardised colour coding practices. Studies of pattern discrimination in remote sensing imagery have been reported comparing the relative effectiveness of semi-automatic analysis techniques and human interpretation (Mower[713]; Brooner[714]; Neumann and Simonett[715]) but the independent variables in these studies have been the selection of imagery channels or combinations of channels rather than their colour coding. In the absence of empirical research, the colour coding practices in remote sensing imagery which will gradually evolve and become established in common usage, may be non-optimum in terms of human performance criteria, in the same way that elaborate, complex colour codes have become accepted on geological maps, without any evidence to support their selection or confirm their efficacy.

11c ADVANCES IN DISPLAYS

Most contemporary aircraft rely on electro-mechanical instruments for presenting information to the pilot. Recent developments in electronic displays have resulted in the increased use of flexible format cathode ray tubes for presenting primary flight and navigation information in advanced cockpits, relegating most electro-mechanical flight instruments to a secondary, stand-by role. The major technological trends have been to reduce the size, weight, complexity and costs of electronic displays, and to increase their ruggedness, reliability, resolution and luminance range. New forms of solid state, flexible format electronic displays have shown considerable potential for future applications, notably light emitting diodes (LEDs), plasma panels, liquid crystal displays (LCDs) and electroluminescent phosphor displays. Important improvements in the utilisation of airborne CRT displays have also occurred, intended to save cockpit space, integrate information and ease the operator's task. Head-up display (HUD) of primary flight information is a feature of many recent cockpits; helmet mounted display (HMD) of weapon aiming sights, primary flight information, and sensor imagery will become common in the near future; electronic head down displays (HDDs), with flexible, multi-function, multi-sensor capabilities are now available offering an integrated, accessible format for digital aircraft systems management. Future developments are mostly aimed at improved pilot utilisation and interpretation, such as stereo television, holographic displays and colour imaging capability. Major trends in aircraft displays have been summarised by Hearne[415] and Lovesey[716]. Applications of individual developments are reported in AGARD Conference Proceedings CP-55 (AGARD[717]), CP-96 (AGARD[718]), CP-167 (AGARD[379]) and CP-201 (AGARD[719]). A comprehensive study of the human factors literature relating to electronic displays (Semple et al.[720] has been summarised by Burnette[721]: topics include flicker, visual acuity, display resolution, luminance, alphanumeric legibility, scale legibility, information coding, display size and the effect of environmental variables on these factors.

Progressively more automated methods of displaying cartographic information in cockpits have been introduced as navigation systems have become capable of indicating the aircraft's present position on a moving map display (MMD), driven from the navigation data source. Three basic types of MMDs can be distinguished:

(1) **Direct View Map Displays.** These take the form of a strip map on motorised rollers with a cross-track cursor indicating present position, or a fixed map with moving cross-wires showing the aircraft's location.

(2) **Optically Projected Map Displays.** A microfilm transparency of a hard-copy map is back-projected onto a screen. The aircraft's present position is indicated either by a moving symbol against a fixed map image, or by a fixed symbol against a moving image (Honick[67, 624]). A prototype laser-hologram projection display system is described by McGrath[160] which dramatically increases map storage capacity.

(3) **Electronic Map Displays.** The information displayed is generated by electronic techniques (McGrath[160]).

Hybrid combinations of electronic and optically projected displays have also been developed in which the map information is back-projected onto the phosphor by rear-port projection or superimposed with the electronic display image by means of a combined mirror and lens system, (Webb[376]; Braid[344]; Dure[377]; Bass[353]; Suvada[378]).

Examples of different types of MMDs are described by McGrath[160]; the same discussion is reproduced as an Appendix in Carel et al.[196] together with survey data on the characteristics of 90 different map display systems. A number of papers on moving map displays appear in the proceedings of two JANAIR Symposia (McGrath[68, 69]).

The main advantages of moving map displays have been listed as follows (Taylor[338]):

(1) *Workload.* They reduce pre-flight planning time and provide an immediate continuous monitoring of the aircraft's geographical position: hence, navigation workload and head-down time in the cockpit are reduced and the pilot can devote more attention to control of the aircraft (Bond[374]; Roscoe[166]).

(2) *Correlation of Navigation Systems.* Map displays provide a means of cross-checking the outputs of navigation systems (INS, doppler, radar, etc.) and visual reference to the ground.

(3) *Man-Computer Linkage.* Map displays are a convenient means of communicating with the on-board navigation computer, checking its integrity, updating its accuracy and entering navigation problems.

(4) *Map Storage.* Map displays store and display large areas of mapping at a variety of scales. Up to 280 m^2 of mapping can be stored on some MMD filmstrips covering the entire operational range of the aircraft.

(5) *Navigation Data Storage and Interpretation.* A variety of navigation information can be stored and displayed in addition to maps, e.g. trackmarker, steering information, digital read-outs of positions and speeds, and distance, time and bearing from destination. By presenting this information superimposed on a map, the integration, correlation and interpretation of data are improved, and the probability of gross navigation errors is reduced (Lewis and Anderson[354]; McKechnie[306]).

(6) *Anticipation.* A map display can improve the ability of the user to anticipate and recognise checkpoints seen on the ground or on radar, and thus provide a timely updating.

The following discussion of various map displays reflects the emphasis of the research effort devoted to them.

(1) Direct View Displays

The principal advantages of direct-view displays are that they can be used with standard paper charts and that they can be readily annotated with flight plan and tactical information. Being lightweight, portable and comparatively inexpensive, they are particularly suitable for civilian and commercial applications and for military transport, helicopter, and maritime reconnaissance operations. Their main disadvantages are that the map storage capacity is limited, that the orientation of the chart is fixed, and that heading or steering information is difficult to display. The time required to prepare a strip chart is a major limitation of roller map displays. More advanced displays have an automatic map changing facility: when the aircraft symbol reaches the edge of the strip, the symbol is repositioned and the next map frame is automatically slewed into position.

(2) Projected Map Displays

Projected map displays (PMDs) are better suited to fast jet operations because the microfilm storage allows a large area of mapping to be displayed consistent with requirements for operational range and tactical flexibility. Modern PMDs have a fixed aircraft symbol which can be displayed in a centred or decentred position, with the map moving in either a north-up or track-up mode (Taylor[338]). The track-up mode with the aircraft symbol decentred to give maximum look-ahead is the standard operational configuration.

The question of whether the map or the present position indicator should move has been a major design issue. Image speeds of map displays do not significantly degrade visual acuity so a fixed display was not predicated (Carel et al.[196]). Empirical research indicated that the operator conceived of the earth as the fixed component against which the aircraft symbol should move (Payne[427]; Roscoe[166]). In practice, most operational displays have a moving map format partly because the "view-ahead" distance needed to be maximised and held constant and partly because of the undesirability of frequent, sudden changes in the map when the moving map symbol neared the edge of the display.

The inability to annotate the map image with route-plan and tactical information has been the major criticism of PMDs. Methods of photographic annotation have been sought (e.g. Fromm and Gray[685]) but none have been implemented in practice. As a consequence, although PMDs show the pilot his present position and the bearing to his planned destination, they do not indicate the aircraft's progress along the planned route in position and time. Annotated hand-held maps have to be carried for this purpose and these tend to be the primary reference in flight; the map display is consulted only to check the aircraft's position. This procedure seems to work, but the pilot must spend valuable time marking-up maps prior to flight, and in flight one of his hands is occupied most of the time holding a map, with the associated problems of stowage and illumination at night. However, the problem is not intractible. Displays are now available that optically combine a CRT with the projected map image, permitting automatic superimposition on the map

of CRT symbolic information, waypoints, tracks and tactical data. The Ferranti Combined Map and Electronic Display or COMED (McKinlay[692]; Aspin[386]) used with the Ferranti Autoplan and PODs system presents an elegant solution to this problem (McKinlay[689]).

Minimising the cost, weight and size of PMDs is important in their design. Hand-held maps can be viewed head-up or resting on the pilot's knee or knee-board, and they do not need a designated space for display in the cockpit. Some small, direct-view roller map displays have been mounted on the coaming of aircraft instrument panels to minimise head-in-cockpit time and facilitate ground referencing (Lewis and de la Riviere[360]) but, as discussed in Chapter 5a, most PMDs occupy a position low down in the centre of the instrument panel. Some have argued that it is psychologically appropriate to position horizontal situation displays in a horizontal or near-horizontal orientation (Bond[374]): but any real operational advantages of such an arrangement are likely to be outweighed by the disadvantage of having to make frequent, extended head and eye movements, particularly at low altitudes when even brief glances into the cockpit can endanger flight safety. On the other hand, the comparatively large amount of cockpit space occupied by a PMD (a 150 mm diameter face is common) is difficult to justify for a single display function in positions higher up on the instrument panel (Eddowes[375]). Again the solution to the problem probably lies in flexible, multi-function, combined displays, such as the Ferranti Combined Radar and Projected Map Display (CRPMD) (Braid[344]) or all-electronic displays in which a variety of information can be presented in an integrated format or on a time sharing basis, depending on phase of flight. Head-up display of PMD images is possible in principle; this could be achieved with a reverse format black-map but many conventional symbols would be too small to be resolved against the complex, dark background afforded by the out-of-cockpit view. A helmet-mounted display has been proposed as a possible solution to the PNG map legibility problem in which a static projected map image is injected into one of the PNG eye-pieces.

The provision of filmstrips for PMDs has required new photographic processes for continuous-flow copying, rectification and printing (Honick[144, 171, 168, 146]; Boot[167]; Defoe[169]; Ferguson[170]; Mueller[722]; Steingard and Choha[723]). High contrast, high resolution, stable, fading-resistant films were necessary to maintain contrasts during extended use, and the material also needed to be sufficiently robust to withstand the unusual mechanical forces involved in moving maps. Non-standard films have been necessary to meet these requirements and in some cases this has meant that deficiencies in colour rendition have had to be accepted (Taylor[371]).

Many factors affect PMD legibility including aspects of the displays, the environment, and the original cartography. Display factors determining the resolution, size and contrast of the image have been discussed by Taylor[642] and by Carel et al.[196] who provide quantitative guidelines for the design of legible map displays. Briefly the resolution of the final image is dependent on both the film and lens resolutions. It can be shown that simple forms of alphanumeric symbols can be theoretically resolved by a system of 3-4 line pairs laid across the symbol, if it subtends more than 6-8 minutes of arc. More line pairs are required for symbols in non-optimum fonts or with low contrasts. Most PMD resolutions fall between 4 and 6 line pairs per mm.

Within the resolution limits of the microfilm and projection system, the map information actually resolved is determined by the degree to which the maps are photographically reduced onto microfilm, and optically magnified when projected. Comparatively high linear reduction factors of about x 15 are common because of the need to provide a large area of map coverage. On projection, factors of optical magnification greater than microfilm reduction (i.e. over-magnification) are used to compensate for the abnormally long viewing distances of panel-mounted displays (approximately 760 mm) compared with hand-held charts (variable, up to 500 mm). Recent displays magnify the map image by linear factors as large as x 1.63 to achieve this effect. Over magnification has the disadvantage of reducing the "view-ahead"; for light jet aircraft the minimum may be at least 20 nautical miles equivalent to 65 mm at 1:5,000,000 scale, and 130 mm at 1:250,000.

High image contrasts are important for PMD legibility. Ambient cockpit illuminations of the order of 3,000 cd/m^2 and reflections off the display face tend to wash-out the map image unless high contrast films, bright light sources and anti-reflection screen coatings are used in the display. The Ferranti Harrier PMD uses a field lens optical system forming the primary map image within the display where it cannot be reached by extraneous light. Light can only enter the display through the exit pupil of the lens system, which is the pilot's normal head position, (Briggs[414]). However, the limited viewing angle of the field lens system limits the pilot's head movement and indifferent optics easily result in image field flatness problems and geometric distortion of the map image (Taylor[338])

The unsuitability of conventional large scale topographical maps for PMD applications has long been recognised (Honick[67]; Briggs[414]). Reverse-format "Black-maps" were suggested by Roscoe[166] as a means of preserving night vision by restricting the light transmitted to information items only. In practice, the effects on night vision are minimised by dimming the display, either electrically or by superimposed filters. Despite user criticisms of content and coding, conventional maps continue to be used in most operational PMDs: Carel et al.[196] recommend design guidelines for PMDs on the assumption that conventional cartography will continue to be used. Experiments have shown that special purpose PMD maps with high contrasts exaggerate physical dimensions, with reduced content and clutter, and with colours chosen that are optimum for the film and photographic process can produce significant improvements in map reading performance (Taylor[100, 642, 641]). It is interesting to note in this context that a survey of users of a variety of PMDs found that the only PMD whose chart image was considered to be reasonably legible was the one PMD that used a specially designed map (Carel et al.[196]).

(3) **Combined Radar and Map Displays**

The principle of a combined CRT and projected map display was first described by Webb[376]. Combined displays are now available that are capable of radar-map matching such as the Ferranti Combined Radar and Projected Map Display or CRPMD for Tornado (Braid[344]) and the Ferranti COMED which through its CRT is capable of generating electronic symbology and both a raster and cursively written radar picture. Radar-map matching has particular advantages when flying at night or in IMC when radar is often the only reliable source of terrain information. Radar imagery from low flying aircraft can be difficult to interpret, even under the most advantageous conditions. Superimposition with a map of the same scale and area, moving in synchronisation with the radar imagery, increases radar interpretability, facilitates the early recognition of features particularly when they occur in radar "shadows", permits continuous monitoring of the navigation sytem, and allows updating of errors in the navigation system by manual slewing of the map image to achieve synchronisation.

Although the principle is attractive, certain sources of difficulty can be foreseen:

(1) If the proportion of visible features common to both patterns becomes small in relation to the total information content or visual content of the patterns, the matching errors made will increase, and with very small proportions of material for matching, reliable performance may become unattainable.
(2) If the features for matching do not take similar visual forms on both sets of material to be matched by superimposition, a common visual pattern may no longer be recognised as such, and therefore become useless as a matching aid.
(3) If the material within one or both of the patterns for matching is visually similar or uniform, then this will limit the extent to which it can be structured visually and hence perceived as a pattern at all, thus limiting matching.
(4) If on one pattern, individual features are coded in a visual form which does not resemble the corresponding appearance of the same features on the other pattern, this may prevent or curtail matching, and, at the very least, will make it a slower process, reliant on memory, since such coding does not naturally form part of the immediately structured pattern or gestalt of the material, and the matching has to depend on processes of induction and deduction instead of on the quicker processes of perceptual structuring.
(5) If the most prominent visual features in one pattern have no corresponding features or no features of equivalent prominence in the other patterns, this will limit the efficacy of matching, increase the time needed for succssful matching, and promote certain characteristic matching errors.
(6) If the visual balance of the material, which is a main influence on the patterns perceived, is different in the materials to be matched, this will reduce the apparent similarity of the patterns being matched, to the extent that with gross differences in visual balance, the patterns may ultimately become unrecognisable as equivalent.
(7) When patterns are superimposed, and are not of identical visual texture, it is necessary to ensure that information on one cannot wholly obscure information on the other, since for matching purposes *both* patterns must remain substantially visible.

Diamantides[674] explored means of cross correlation between a radar display and a reference map so that it would be possible to determine unambiguously both the magnitude and direction of positional offsets, and hence to correct mismatches. He suggested a form of analogue to digital conversion for continuous tone pictures, which would permit quantitative descriptions and facilitate matching (Diamantides[675]). Although his interest was primarily speculative and theoretical, he did include a simulated demonstration of the principle. A parallel process is the systematic study of radar information to determine what kinds of discrimination can reliably be made with it. The study of Marain and Simonett[724] provides an example of this kind of work, showing that certain broad types of vegetation may be discriminated on radar, with the aid of suitable collateral material. Emery[315] concluded from his studies of helicopter flights that although an experienced radar observer could glean considerable information from radar imagery, the fact that the same radar return could represent a variety of features placed limitations on the interpretations he could make.

Braid[344] described the processes for using a radar map-matching display. He emphasised that the purpose of the map was to enable a particular radar return to be positively identified by positioning an electronic marker over it and then expanding the picture to permit greater precision of marking and hence updating the navigation information. The claimed benefits of this marking method were:

(1) The positive identification of radar features.
(2) The elimination of gross navigation errors.
(3) The saving of cockpit viewing space by superimposition.
(4) The negligible increase in weight, cost, complexity and operational procedures.
(5) The reduction of crew workload.

He emphasised that the radar-map matching system did not require greater accuracy than the radar or map alone, but did permit the correlation of true position with position calculated by the aircraft's navigation system, and the correction of any discrepancies. The two navigation aids which made radar-map matching practical were inertial navigation and projected moving map displays. Braid concluded by emphasising that the aid did not improve the quality of the radar picture and was not intended to do so, but it did lead to a marked improvement in the interpretation of the radar display by the aircrew.

One of the basic design problems with combined displays such as CRPMDs and COMED is to achieve a combined image in which the radar returns or symbology are sufficiently bright to be seen against the map image. Field lens/transfer lens optical systems go some way towards achieving this by making the combined image independent of ambient brightness. Aspin[386] points out that the brightness of the 3 inch diameter CRT in COMED is 2 x brighter than a full size 6 inch tube with equivalent drive power. Another possible solution is to reverse the format of the map so that the background is predominantly dark with the the information items overprinted in light colours. A variety of reverse format "black-maps" have been produced and evaluated in a CRPMD simulator at the Royal Aircraft Establishment, Farnborough. Ad hoc assessments have shown that although black maps optimise the brightness contrasts of overlaid radar, they are at a serious disadvantage compared with conventional formats with regard to relief information. In mountainous regions, relief features provide the only useable radar returns, such as reflections from steep slopes and ridges. Hill shading is the best method for showing relief slopes, but it is incompatible with a black-background map (Taylor[338]).

The maps available for radar map matching were not designed for that purpose, and tended to be deficient in contrast and overdetailed in content. The Joint Operations Graphic was so unsuitable for this purpose that radar map-matching would be "virtually valueless if the JOG(Air) edition remained the only topographical mapping material available" (Barratt, Doidge and Honick[345]). These authors conceded that appropriate mapping would have to be achieved speedily with minimum cartographic effort and cost, and that redrawing was therefore impractical. This left selective omission of printing plates and changes in the colour rendition of individual plates as the only practical means of altering the appearance of the JOG map to make it more suitable for radar map matching. Colour changes were introduced for hypsometric tints, town fill, major roads, sea, major airfields and power transmission lines. Strong hill shadow was introduced. Numerous categories were omitted: text, minor roads, woods on high ground, grid information, most boundaries, railway stations, isolated buildings, minor rivers, minor airfields, and several features, particularly those of vertical significance such as windmills and churches. The results were a spectacular improvement, demonstrating conclusively that a map suitable for radar map matching could be derived from the JOG series without redrawing. The hill shadow combined with a series of warm brown hypsometric tints seemed particularly successful. While this assessment was subjective and was not intended to establish a principle, it gave sufficient encouragement to suggest that further work to approach an optimum map specification, derived for the JOG and intended for radar map matching, might well be productive, entailing as it does relatively little cartographic effort.

(4) Electronic Map Displays

Electronic map displays in which the cartographic information is generated by electronic techniques have only become feasible as a result of the comparatively recent introduction of large capacity digital computers in aircraft (McGrath[160]). Electronic displays of cartographic information have been available in ground environments for some time, such as for interactive editing of digital cartographic data bases. All-electronic systems should be more accurate and reliable than optical/mechanical systems because they have no moving parts and rely only on digital signals. Also, they should be more flexible than optical/mechanical PMDs since the display content, scale and format can be altered by software changes instantly available at the press of a button. Costs and the computer capacity required to drive them are the major limitations; problems of brightness, contrast, flicker and resolution can all be overcome with existing techniques.

According to McGrath[160] several calligraphic CRT systems have been developed (e.g. the Electronic Astro Chart System P/N 142000) but none are in service. None has a colour capability, which must be a considerable disadvantage compared with PMDs, and none of them are capable of presenting extensive cartographic detail. A colour TV map display system could be achieved by recording the map information on a colour video magnetic tape for airborne display or by a vidicon camera remotely scanning a map filmstrip.

Hitchcock[527] reports research on the legibility of type on a colour and black and white TV map display system using videotape map storage. Black-and-white display tended to give superior performance in low contrast areas of the map; lettering tended to blend into the background in mountainous terrain where hill shading was used to indicate relief. He concluded that characters for videotaped maps should be large enough to subtend at least seven raster lines. McGrath[69] has also discussed cartographic factors in the design of a colour TV map-display system. He recommended that the display should provide the finest colour discrimination among the browns and greens, that colour discrimination among reds will be least important, and that an attempt should be made to enhance the presentation of blues. Experimental data on the relative legibility of symbols on existing charts viewed on a TV monitor are reported by Wong and Yacoumelos[528].

McGrath[160] also reported feasibility studies on map displays using transparent electroluminescent panels and transparent plasma panels with light emitting diodes. Colour imaging will not be possible but the main advantage would be that the display need only be a thin board suitable for use in light aircraft.

11d THE ROLE OF COMPUTERS IN CARTOGRAPHY

Computers influence aviation cartography in two distinct ways. Firstly, computers are revolutionising map production technology; in this role, computers have the same effects on aviation maps as on other kinds of map. Secondly,

ground-based and airborne computers have increased the automation of navigation and altered the methods of map display and map usage in the cockpit; in this role the effects of computers are specific to aviation maps and their conditions of use.

Automated Cartography

Automated cartography has advantages over conventional production methods in terms of man power requirements, costs, speed and accuracy. The flexibility of the digitised data bank is a fundamental technological advance (Rhind et al.[519]). Engraving time can almost be eliminated with a suitable computer and graphic output device (Thompson and Min[725]). Kay[726], in proposing a method for transmitting aeronautical charts electronically, anticipated some of the major potential advantages of computer-based cartography: fast and frequent modification of data, and quick production of amended products. The willingness of cartographers to accept and use drastic technical innovations such as those based on computers was identified by Heath[147] as a main determinant of progress in cartographic display quality and data accuracy. In general, cartographers have often shown themselves to be receptive to computer innovations, particularly since automation may permit increased cartographic productive capacity without a corresponding increase in man-power (Harris[727]). Misulia[372] recalled that digitised maps were initially used for weapon and radar deployment, for line of sight calculation, for mathematical modelling, and for producing three dimensional terrain models. The next stage was to produce terrain elevation data from aerial photography. Goals at that time were the derivation of terrain models directly from computer tapes, and the transformation of photographs directly into computer language. He envisaged very rapid major extensions of computer-based technology for the provision of mapping for specific military uses, so that the cartographer of the near future would be able to meet military requirements on time with a high quality, operationally efficient product. At present the major non-cartographic military applications of digitised topographic information are for producing radar predictions for simulation, and in flight training, for briefings on operational sorties, and for terrain contour matching matrices (Steakley[373]).

The impact of computers on map production has been described by Keates[120] who devoted separate chapters to image formation and to map compilation. The theoretical basis of computer cartography is reported by Peucker[140]. Keates[120] noted that in automated cartography the data must be digital.

Automatic image formation entailed the provision of suitable information for the computer, automated positioning of the image-producing device, and an automated means of forming the image, whether by drawing, by scribing and cutting, or by transformation by means of an appropriate sensitised material. Every digitised item must be specified in terms of what it is (phenomenon), and where it is (location). Alternatively, an automated optical scanning process may be employed, although this is potentially more suitable for material in picture form with continuous tone backgrounds, such as orthophotomaps, than for conventional maps where, even in high density regions, much of the scan covers featureless background and is assigned zero values. Automated processes have been extensively developed for continuous line plotting, but can be extended to point symbols, either by treating point symbols as a variant of lines or by optical exposure using templates.

In considering automated map compilation, Keates[120] distinguished between automated acquisition and digitising of data, and automated processing of data according to a particular map specification. Intermediate between these two aspects of automation in map compilation is the data bank, the product of the first aspect and the basis of the second. World-wide maps are derived from heterogeneous cartographic sources, varying in reliability, quality, detail, consistency and projection, and to assemble all the data into a uniform digitised format in order to form a data bank is a vast undertaking. Once achieved, however, the benefits are commensurate. Supplementary computerised facilities may be needed to compile maps from the data bank, including indexes to source materials, to regions, to specified cartographic information categories, or to projection systems. Various methods for digitising cartographic data may be adopted, and these are outlined by Keates[120]. Compilation may be semi-automated, in which computer assistance is provided for various manual functions, or fully automated, where the map product is derived automatically, directly from the data base. The data may be addressed and selectively modified by interactive control, through a CRT visual display unit which presents the cartographic data to be addressed and is linked to a selective control facility to make additions, deletions and emendations.

The feasibility of automating so many aspects of map production demands decisions on how automation can be applied most efficiently to maps. One approach to computerised mapping is to attempt to identify which human functions in using cartographic information could be fulfilled adequately by a computer (Aumen[728]). This presumes that cartographic information exists in the form of a digitised data base, and that the cartographer is able to employ a thorough understanding of how his products are used in deciding what functions required digitised mapping (Gilbert[729]).

One problem in the automation of map compilation is the efficient and unambiguous classification of the features which constitute cartographic categories, in terms which can be digitised and selectively specified. The implications for the visual appearance of the final computer-generated map product of selecting digitised information categories also have to be deduced. The principles for the specification and quantisation of visual patterns, symbols and forms for computer storage have been discussed extensively (Lipkin and Rosenfeld[730]), and some have tended to persist although subsequent developments may have produced superior techniques. Methods of line storage include the x,y co-ordinate method, incremental coding, chain encoding whereby a line is represented by a series of short quantised line segments (Freeman[611]), and skeleton coding whereby any area is defined by a set of rhombi (Pfaltz and Rosenfeld[731]). An

alternative approach, considered to be applicable to maps, was to treat the pattern as a whole, subject it to a series of transformations, calculate the invariants, and introduce a variety of normalisation transformations to render the resulting signal independent of various factors in turn (Guiliano et al.[732]). The relative merits of different methods of line storage are discussed by Peucker[140].

A variety of graphic output devices can be used to display cartographic data stored in a digital form. Line printers are the most readily available devices. A line printer can print very fast – up to 2,000 lines per minute – but its drawbacks are its low resolution and relatively quick fading of the carbon ribbon. Electrostatic line plotters have eliminated these disadvantages, but the paper it vastly more expensive than printer paper. Drum plotters and flatbed plotters which draw lines defined by a sequence of co-ordinate pairs, are preferred by most computer centres because of their greater versatility in terms of resolution, speed, and multiple-pen heads. Cursively written CRTs are used as an intermediate display for interactive editing in some systems. They are very fast in response, and can be used for dynamic presentations (Moellering[733]), but unlike raster written CRTs, they do not display grey-tones. Hachuring is almost impossible and the line-work is generally too coarse and complex for the production of most final maps (Peucker[140]).

Until recently, the graphic quality (generalisation, simplification, resolution, tonal quality, etc.) of most computer drawn maps has been relatively poor compared with most manually drawn products. Examples of the most widely used system, SYMAP, developed by the Laboratory for Computer Graphics and Spatial Analysis, Harvard, are given in Peucker[140]. Improvements in output devices and software are likely to increase their market potential but at present the main use is in the area of thematic mapping for the analysis of statistical surfaces census data, spatial trend analysis etc. Here, speed of production and flexibility of the format of the display from a given data base are a major advantage over hand-drawn techniques. Computer-drawn stereoscopic presentations (Adams[163]) and three dimensional representations of statistical and topographical surfaces with rotation of perspective, such as SYMAP/SYMVU programs (Worth[734]), provide an attractive alternative to conventional planimetric two-dimensional views (Breme[626]; Jenks and Steinke[735]) but it has yet to be demonstrated whether they offer any real advantage in terms of improved map reading performance (Worth and Board[736]).

Computers for Aircraft Guidance and Control

Computers have an important role to play in future command and control systems for airspace management. General problems of command and control computer systems in aviation are discussed by Oliver[737, 738]. Recent developments in lightweight, airborne digital computers with mass-storage, high-speed, high accuracy computational processing capabilities have revolutionised many aspects of aircraft guidance and control. It has been suggested that maps may also be generated by computer for use in air defence, air traffic control or guided weapons systems, where maps, particularly of coastlines and air information, are used as reference and back-ground material (Webber and Hopkin[739]). Computer-generated map data may also be combined with other sources of information, such as rear port displays (Robertson and Savill[740]).

In airborne systems the computer is responsible for processing sensor inputs, and by predetermined guidance and control laws, it is able to solve navigation problems, provide guidance cues for the pilot or automatically fly the aircraft to predetermined destinations. The accuracy of computation is limited only by the accuracy of the input data: systems with multiple high-resolution sensors and stored digital terrain information are now available that can provide data with sufficient accuracy for fully automated navigation and weapon delivery. Martin[741] lists the following advantages of digital mechanisation of flight control electronics, most of which are applicable to navigation and guidance:

(1) Digital signal transmission and multiplexing and the ability of the computer to time share hardware elements reduce the quantity of hardware required for management of fault tolerant systems.
(2) The precision of digital processing, combined with the ability to employ signal selection on all input sensors, allows tracking of multiple channels. Large tolerance buildups which complicate the control and monitoring of redundant servos are avoided.
(3) With the digital computers' superior capability to execute logic functions, more complete and less costly system test is possible. In flight, the built-in test and monitoring functions permit easier detection of failures so that they can be isolated and identified for post flight maintenance.
(4) Flying qualities can be improved by using control laws not feasible with analogue systems because of processing and accuracy requirements.
(5) There is improved flexibility to make changes during both the development and service life of the system.

An analogue aircraft navigation system and map display is described by Briggs[414]. The main advantages of digital systems compared with analogue systems can be attributed to the increased computational speed and accuracy of the stored programs and the improved software flexibility. With digital navigation systems such as COMED (Aspin[386]; McKinlay[689]) a flight profile can be entered manually or automatically and then flown automatically with digitally stored route plan and tactical information displayed and superimposed on the map image. Large numbers (up to 100) of waypoints, identification points and targets can be stored and called up for display with computed steering information from the aircraft's present position. At present the main problem seems to be in ensuring that the man-computer interface is designed to facilitate data entry and accession in ways that permit simple and safe operation in flight with minimum head-in-cockpit time. Many contemporary map displays, for instance, have numerous complex operating modes, but there is no immediate indication on the display of the mode currently in use (McGrath[160]). The acceptability of future

all-electronic systems using a digital cartographic data base will depend a great deal on interface considerations, such as data entry and colour capability, and on the extent to which the flexibility in content coding and emphasis is utilised by software developments.

Automatic terrain contour matching by airborne digital navigation computers has been described by Steakley[373]. The combination of doppler radar and radio altimetry makes it possible to measure aircraft altitudes with exact spacings for the accumulation of topographic profile recordings. Such profiles are sufficiently unique to be correlated with the same profile stored in the aircraft's computer to give accurate line-of-position fixes for updating inertial navigation system accuracy. The stored data could take the form of a terrain elevation matrix of data points at close intervals, say 1,000 feet. For a given terrain model, the size of the data base will depend on the computer storage capacity. Until recently, storage limitations and data access times have severely restricted the feasibility of terrain contour matching to relatively small corridor of terrain, e.g. the cruise missile concept. A technique has now been developed, known as a polynomial terrain model, for compact digital storage of elevation data which also decreases the data access time significantly (Jancaitis[742]). Also the computer industry has been experiencing dramatic increases in processing speeds and digital storage capabilities along with steadily declining costs. Some of the potential applications of near and real time digital terrain data for simulation training and in flight display are illustrated by Jancaitis and Moore[743].

The enhanced production capacity and increased speed and flexibility in meeting users' cartographic requirements, together with the great variety of cartographic products which can in principle be derived from a data bank, pose questions on how advanced computer technology should be harnessed and how it may be employed to ensure high quality in cartography. Keates[484] pointed out that the ability to handle more information does not necessarily imply that the user is better informed, merely that he is more informed. The map needs selection from the data bank, but the quality of the product as far as the user is concerned depends a great deal on how carefully the cartographer has examined the topography, decided what is needed on the map, and portrayed it. He cautioned that "the present passion for converting map information into digital form, often at great expense, only makes sense if we are quite sure that this information is really what it may appear to be, and there is some concept of its operational value". There does seem to be a tendency to digitise information because it exists, rather than because it is needed. Such digitising also raises the questions of what a map is and what it is for, and reveals the paucity of accepted cartographic theories (Molineaux[477]).

CHAPTER 12

SOURCES OF DIFFERENCES BETWEEN AVIATION MAPS

Numerous definable influences lead to differences between aviation maps. The content and appearance of any given aviation map are primarily determined by these influences collectively.

A classification of the sources of differences between maps may serve several purposes. It can indicate what kinds of differences can be expected between aviation maps, how large the range of differences may be, and what factors have affected the differences which occur. By gathering together the main causes of differences between maps it becomes possible to assess their relative importance. The extent to which aviation maps collectively fulfil all their objectives can be appraised. The nature, magnitude and range of differences between existing maps can be examined. The interactions between human factors requirements and the possible ways in which maps can differ may be studied. The residual characteristics common to all aviation maps may be clarified.

The number of sections within this chapter indicates that many influences on maps can be traced, and that many disparate factors exert some influence. The interactions between these factors are intricate. In theory it is essential to define the map functions first and then to deduce what form the map must take, bearing in mind cartographic methods and conventions. This is in principle quite straightforward, since the stated functions imply what information must be shown, with what relative prominence, in what detail, and with what accuracy. This in turn suggests the appropriate scale and level of generalisation. Functions are influenced by stated preferences of users, in so far as these are not incompatible with efficiency, and both display technology and collateral material influence the functions which can be fulfilled.

12a INTENDED FUNCTIONS

In theory, the functions are the main influence on map design; in practice, the map design substantially affects its functions. Rather than successfully fulfil predesignated functions, the map may be used to serve those for which it proves adequate, while others go unfulfilled. This often occurs when there is insufficient evidence available at the time of map production on how the map will be used. Although it has long been acknowledged that a number or "family" of aviation maps should be designed collectively on logical principles, so that together they fulfil all envisaged requirements and each is optimised for a group of uses (Dorny et al.[21]), in practice this intention is seldom realised. Each map tends to be designed piecemeal without close scrutiny of whether its functions overlap with others' or whether certain functions remain unsatisfied because no map can fulfil them. Operational requirements for maps are constantly changing. The processes of designing and producing maps and revising specifications take so long that the adequacy of maps in fulfilling existing functions will depend on the extent to which the functions are stable or the changes were anticipated. In practice, revisions, redesigns and new series are initiated when existing maps prove inadequate in operational service. There are no good reasons for assuming that this must continue to be the case, given a better understanding of how maps are produced and used.

If the intended functions of aviation maps were the dominant influence on their design, the number of different aviation maps would be far larger than it is. The specific requirements of each type of mission, each task, each aircraft type, each display innovation and each kind of map user could in principle be met by a different optimised map specification for each subset of conditions. The resultant number of map series would grossly exceed production capacity. Considerations of expediency, practicality, effort and cost preclude the production of the ideal map for each occasion. The concept of a dual purpose compromise design for projected and direct viewing has been discussed only recently in relation to the UK proposals to revise the TPC, which are based in part on recent research at the Royal Air Force Institute of Aviation Medicine, Farnborough. Some attempts to meet novel operational requirements may seek to use existing map series rather than evolve new specifications, but often requirements for maps for specialised purposes, such as radar map matching, attract proposals which are novel because they come from non-cartographic agencies. Prevailing proclivities are to have far fewer maps than functions, and to fulfil each new requirement with an existing product whenever possible.

Although it can be contended that, as a consequence, no map will ever be ideal for any single purpose, it does not follow that the whole approach is wrong. Aviation maps are not intended to be ideal, but to meet requirements adequately. Excessive proliferation of maps would lead to several predictable and unacceptable operational consequences: more maps would be needed for pre-flight planning and more would have to be carried in the cockpit; there would be greater confusion between different map series; it would be easier to choose the wrong map for any given purpose; locating the desired map among others would become more difficult; it would be necessary to learn more detail about

the content and method of portrayal of each map series; confusions could arise between users of different maps; users would be less likely to become fully familiar with any one series; etc.

Special-purpose maps cannot be precluded but since most maps must meet several needs, aviation maps as a whole can be judged by the success with which all needs are catered for by maps in regular use. Each map must fulfil a clearly defined group of functions. There should be no required function for which there is no suitable map; nor should there be any function for which more than one map would be equally appropriate. Relationships between functions have to include not only the needs of each user for his primary tasks, but also the need, in tasks such as liaison and tactical support, to convey the information on one map to others who may not possess the same map.

No two map series should be very similar. The magnitudes of the differences between map series should not be random, but be about equal and be logical. When new maps are proposed, it is essential to define their objectives clearly and to state where they are intended to supercede existing maps. It is not advisable to meet a new cartographic requirement in isolation, without discovering if further functions could also be fulfilled by minor revisions to its specification. If for one function it proves necessary to depict power transmission lines for example, it is sensible to consider which further functions might benefit if power lines were shown.

Despite the difficulty of providing adequate cartographic support for all aviation tasks, there appears to be considerable duplication of cartographic effort. Some justifiable duplication takes the form of experimental sheets to illustrate the effects of proposed changes in portrayal. Nevertheless it is disconcerting when a far from exhaustive search finds eighteen different maps of the same region at the same scale with substantially the same information on them (Taylor[222]).

Classifications of the functions of maps must take cognisance of their role in relation to other navigation documents (Ryder[381]), of the expressed wishes of users about the information they need (Murrell[131]) and of the characteristics of maps as information displays (Dornbach[127]). Joint military and civil teams may be advantageous in defining requirements and deciding how they should be satisfied (Sorrentino[744]). One method for defining detailed map functions is that adopted by Wright and Pauley[349]: they considered the limiting factors in a particular mission, how maps could mitigate them, and how the best use could be made of the limited data available. Heath[147] emphasised the role of the visual characteristics of the map in determining its effectiveness for its intended functions. In aviation maps, the functions may need to be fulfilled under disadvantageous conditions, so that it becomes necessary to define how far problems posed by such factors as cockpit lighting can be overcome (Taylor[657]). Some of these points were discussed by Hopkin[70] who was primarily concerned with the application of human factors display principles to map design. He suggested that the multiplicity of functions which each map was intended to fulfil might be incompatible with a single optimum display design.

At the present time, much detailed work on how maps are actually used in the cockpit remains to be done. Many of the relevant studies have been analytical rather than practical, deducing how maps could be used rather than recording and describing what pilots actually do. While deductive methods can be valuable, they need to be supported by empirical evidence, to verify that what is thought to be possible is actually being done. For many functions, the practical evidence of map usage is insufficient to provide the cartographer with an operationally satisfactory map specification. To achieve this requires a great deal of systematic high quality routine work, including task analyses derived from factual evidence. Given this basis, the most successful methods for portraying essential information on the map can be examined in relation to their functions. It is not sufficient merely to provide the information which is essential according to deductive methods. The information must be in a form which the man can use in the time available, which is compatible with such known limitations as visual searching, memory, and information processing, and which does not go beyond the skills and knowledge of map reading which he has been trained to possess.

12b THE RELATIVE IMPORTANCE OF DIFFERENT CATEGORIES OF CARTOGRAPHIC INFORMATION

For any designated use, the information categories on aviation maps should be portrayed in ways which reflect their relative importance. When a map has many uses, a compromise has to be struck among conflicting claims to relative importance. The visual prominence of each information category does not depend solely on envisaged usage and operational importance, because there are other factors to consider. Visual balance should be preserved: the map can have a dull and excessively uniform appearance (Lakin[340]) if, to satisfy its numerous functions, the prominent portrayal of any cartographic categories has been discouraged. The further constraints of dim or red cockpit lighting, a vibrating environment, or short viewing times also narrow the range of visual prominence which can be employed in the portrayal of information on the map. Information which does not stand out, because of small size, low contrast, insufficient weight, etc., or because it is too similar to other information, may not be seen under adverse operational conditions, or may be mistaken for something else. The need to photograph a map also restricts the range of visual prominence of the information on it. The relatively uniform visual emphasis within the symbology of a paper map intended to be suitable also for projected map displays, is almost bound to impair visual balance, and to give an impression of visual competitiveness among different cartographic categories (Taylor[642]).

Aviation maps follow cartographic practice in treating relief and natural features as background and man-made features and air information as foreground, contrasting with the background by being visually more prominent. This

cartographic convention may clash with operational needs, as in low altitude, high speed flight when the terrain can be the most important information on the map and adequate portrayal of its shapes and gradients is essential. This problem of assigning greater visual prominence to terrain shape, and less to point or linear features, has not been satisfactorily solved on existing map series for low altitude, high speed flight. Perhaps no solution is possible without granting a degree of artistic licence which would be incompatible with the requirements of a world-wide series and would sacrifice too much discrete information in order to portray continuous relative changes effectively.

It is vital to ponder carefully the relative importance and relative visual prominence of cartographic information categories, simply because this is the factor which is most readily controlled and manipulated to achieve an operationally acceptable map. Taylor[659] demonstrated that substantial improvements in aviation maps can accrue from changing visual prominence, and that these can be achieved without major re-drawing and without high costs, provided that the aims are clear, and the correct principles for realising them have been followed. Manipulation of the relative visual prominence of categories of map information can greatly improve both the utility and the attractiveness of the map. Not only does its operational worth depend on how well this has been done, but so does its acceptability.

Because of the variety of visual coding conventions which can be employed to manipulate visual emphasis, there are in principle several methods for giving a designated cartographic category the desired visual prominence. For example, if the category is portrayed by a symbol, its size, shape, contrast, weight, density, line thickness, hue, saturation, brightness, or design may be altered, or a different symbol substituted. A corollary of this inherent flexibility in the means to achieve a desired visual effect is that an effect should never be sought in isolation, but always related to others, since the visual prominence of cartographic information categories is primarily a relative rather than an absolute matter. A further corollary is that there should be some prospect of achieving a desired visual prominence by methods which maintain visual balance, eschew solutions near the visual threshold, and foster a pleasing appearance of the map as a whole.

This would be a highly practical way to improve map design, and to ensure that the map is fit for its purpose. It demands a sound knowledge of the purposes of the map, and of the effects on visual prominence of designated changes in the main psychophysical variables, singly or in combination. The requisite knowledge to ensure that the intended effects of manipulating visual emphasis are actually achieved is far from complete. There is some tendency to assume that the relative visual prominence of an information category on the map should be equated with its relative operational importance. Sometimes this may hold true, but the visibility of ground features from the air may be of overriding significance.

Changes in relative visual prominence have often been proposed as practical ways to improve map design. In an early paper on approach and landing charts, Freer[43] claimed that existing methods for depicting hills gave them insufficient prominence on the chart in relation to their operational significance, and he advocated the use of layer tints. Waters and Orlansky[24] pursued the notion that visual prominence on the map should be related to probability of seeing the feature visually from the air, as determined by its angular subtense when viewed from the air. Waters[332] derived theoretical nomographs of the predicted visibility of objects, and proposed a method for verifying them. Howey[336] and Saunders[621, 622] also dealt with visual emphasis in choosing appropriate map symbology.

Direct transformation, from visual angle or conspicuity to significance or visual prominence may not be justified because what is most visible may not be most important because of lack of uniqueness, transience, survey difficulties, etc. The usefulness of depicting features on the map which are known to be too small to be seen from typical operational heights must be limited to missions where such features may be targets, since they are valueless for navigation. Even if a direct relationship between emphasis and importance is agreed to be desirable, there may be difficulties in portraying it to give the intended visual effects. Tests of the effectiveness of symbols in isolation may not yield findings which hold true for the symbols in a map context (Heath[147]). Quantitative psychophysical differences intended to convey to the map user the magnitude of changes on a dimension may be misinterpreted because of systematic over- or under-estimation, for example of apparent size (Flannery[182]). Symbols, easy to read on a conventional map, may lack visual prominence on an orthophotomap (Smith[165]). Attempts at three dimensional mapping must deliberately introduce substantial exaggeration of the vertical dimension, by an amount dependent on contour interval, to enable map users to evaluate such maps correctly (Jenks and Caspall[225]).

Maps designed to portray the relative importance of categories of map information may fail to do so if one of the coding dimensions is no longer available. This problem occurs most commonly when colour coding cannot be used. Some categories may lose so much prominence that they can scarcely be discriminated on an achromatic map (Osterhoff et al.[320]). A further problem was identified by Osterhoff et al.[133] in a separate report: because the portrayal of relative prominence is influenced by the incidence of features to be depicted, and because this varies with geographical region, the effectiveness of the map may be terrain dependent. Furthermore, the assignment of visual prominence may itself have to be relative, since a feature of little operational significance in a region where more important features abound may come to have much greater significance when it occurs in another region devoid of more important features. Visual prominence also depends on the density of mapped features (Hopkin[70]).

12c CARTOGRAPHIC CONVENTIONS AND STANDARDS

Cartographic conventions and standards, being on the whole rigid, are generally a source of similarities among aviation

maps rather than differences between them. Internationally agreed standards (Anon[654]), the users' familiarity with established cartographic conventions, encourage the retention of existing practices even when they are scarcely adequate for new needs. Those changes which are made tend to adapt proved techniques rather than introduce innovative symbology. The main sources of differences between aviation maps which can be attributed to cartographic conventions and standards therefore occur in circumstances where certain specialised maps have had to abandon these conventions while other conventional maps retain them in an unadaptive form.

Differences between maps also arise where a feature can be depicted according to more than one cartographic convention. These alternative depictions need not be visually similar. On some maps, various categories may be depicted by pictorial symbols – crossed pickaxes for mines, outline drawings of large buildings for factories, etc. – whereas on other maps, and even on the same map, the same information is coded by lettering alone, e.g. the words "Large Building". On a given sheet the absence of a specific pictorial symbol may therefore be because no such feature is present on the ground or because the feature is not differentiated in pictorial or symbolic form.

It is possible to treat cartographic symbology as one among many means of representing terrain, and to compare it with graphic and non-graphic alternatives (Imhof[636]). Dornbach[127], considering maps as displays, concluded that the cartographer is most responsible for perpetuating standards and conventions which ensure that the only users who find the map effective as a medium for transmitting information are those who have learned and understood cartographic language. Some differences between maps arise because they vary in the meaningfulness of their language. Berry and Horowitz[515] believed that topographic displays would be more easy to interpret and use if they relied on symbols with a closer pictorial resemblance to the features they represent. Adams[490] traced some of the differences between maps to the use of a variety of conventions, some of which met human factors display requirements better than others. Differences between maps would be reduced if all symbols conformed with minimum psychophysical principles for discrimination. However, the interacting effects of such psychophysical parameters are sufficient to suggest that recommendations should not be based on deductions which do not take the interactions into account.

A theoretical framework to specify the syntax for the language of cartographic symbology was proposed by Morrison[473] who contended that such a framework was essential in developing standardised map symbols. A comparable framework is desirable in using colour coding on maps, and Robinson[98] advocated caution in introducing any new colour coding conventions. A promising approach is to select sets of colours which are maximally discriminable, as established by empirical testing using colours within the compass of cartographic printing technology (Taylor[641]). As cartographic standards and conventions must evolve to match new display technologies and advances in navigation, it is important that symbology does not proliferate, forcing the user to learn more complex and less self-evident meanings assigned to symbols. Further evidence is needed on what is perceptually and meaningfully equivalent for the user. With different contrasts, sizes and colours enforced by the requirements of new developments such as radar map matching and orthophotomaps, the extent to which individual symbols could be retained in their essentials but modified to maintain discriminability under various viewing conditions merits serious attention.

The notion that different cartographic conventions should be employed deliberately for different map series to classify them and aid their recognition has been mooted from time to time. Different colours could be used for town fill on maps of different scale, for example. This notion has not been the subject of research, and some experimentation to explore its consequences would probably be beneficial, if only to dispel it. There seem more than enough cartographic coding conventions to be learned even if they are universal, without gratuitously adding more. The potential advantages of using different conventions for different map series seem far outweighed by the disadvantages incurred.

12d THE REQUIRED ACCURACY OF INFORMATION

Accuracy is a function of a series of stages in map production and usage, including the following:–

(1) The choice of projection system.
(2) The quantity and quality of data available for compilation.
(3) The selection of categories for mapping, and the resultant information density.
(4) Scribing techniques and tools.
(5) The skill of the compiler.
(6) Cartographic printing technology, including choice of paper.
(7) Map scale, content and function.
(8) The user's ability to map read and to interpolate.

It is not always possible on a map to convey its level of accuracy adequately. If the map has been compiled from uncertain data, it may be difficult to indicate that the accuracy is low, particularly with linear and point features which, if they are present, are depicted on the map at specific positions and thereafter accorded a spurious precision. The accuracy of information on aviation maps must not be exaggerated. A prominent feature boldly depicted at a precise location where it does not exist can be dangerously misleading. A frequent critical comment by aircrew is that maps of regions of very low information density can give a wrong impression by exaggerating the number of features likely to be visible from the air, and by failing to convey the featureless nature of the terrain.

From the point of view of the user, it is impossible to depict information as accurately on small scale as on large scale maps. This is because subjective impressions of accuracy are mainly related to visual conjunctions on the paper, and the perception of thresholds, just noticeable differences, and interpolations depend on angular subtense rather than map scale. It is not operationally necessary to have the same accuracy on small and on large scale maps, and factors such as generalisation, associated with progressive loss of detail, mean that accuracy is always relative. Even the largest scale map has some loss of fine detail compared with the terrain it represents. Sometimes accuracy has to be sacrificed in the interests of clarity. An example occurs on small scale maps with several parallel linear features such as roads, railways, and a river in a narrow alley, each depicted by a line the thickness of which, at the map scale, covers a much greater width than the feature itself.

For many operational roles, the efficiency of the map is enhanced by some compromising of accuracy. At the smallest scales, systematic errors associated with the choice of projection mean that certain information is not fully accurate for certain tasks. In general, a consideration of the tasks to be done with a map makes plain what accuracy is needed on it. From high altitude, the general shape of a coastline must be shown so that it can be recognised and identified, and obsessive accuracy in its depiction would lead to excessive fussy detail, invisible from high levels and obscuring the main outline. On the other hand, features which may serve as check points or for updating an automated navigation system must be depicted accurately on the map in order to distinguish them from other similar features. Differences among aviation maps in their requirements for accuracy therefore reflect different envisaged usages. It would not be ideal if the accuracy of all of them was the same. This does not mean that features chosen for depiction do not need to be located accurately on the map but there is no point in relentlessly pursuing accuracy in one respect if larger sources of inaccuracy affecting the same feature, such as the projection system or limitations on vision, are known to be present. For operational uses where patterns of features are sought, perceived and interpreted, the relative accuracy with which features are located may be at least as important as the absolute accuracy of the location of each. Symbology which in the interests of discriminability sacrifices some accuracy in depicting relative locations may not be acceptable.

If the map will be used with fine measuring tools or magnification, great accuracy is needed so that the map contents justify the proposed precision of measurement. If the map will be viewed rather than measured, accuracy far beyond the users' ability to discriminate becomes pointless. The users' accuracy in reading fine scales (Carr and Garner[661]), in reading polar co-ordinates (Green and Anderson[663]), in interpolating spatial locations (Guttman and Finley[420]), in discriminating different line thicknesses (Wright[181]) and in estimating direction from a map (Grey et al.[351]) can be predicted. If the map will be used to measure sinuous linear features, then the methods by which these may be compiled, with their associated sources of error, need to be known (Keates[120]), and the sources of error while using various measurement tools need to be understood and related to them (Maling[745]). Generalisation and scale are among the factors which may affect substantially the accuracy possible in making such linear measurements. Some cartographic conventions, such as hill shading, are inherent sources of inaccuracy in their fine detail, though not necessarily in their general impression, and some of the problems associated with them were discussed by Jenks[746], Harris[157], and Jenks and Knos[94]. Differing land and air requirements for accuracy may be hard to reconcile within a single map (Bennett et al.[114]).

Gammon[113] pointed out that the accuracy of a map need not be a matter of speculation, but that estimates can often be made of the prevailing levels of accuracy which it would be prudent to assume when maps are being used. Means and distributions for errors in drawing can be quantified, and those for other sources of error estimated and combined with them. With such information, the true operational value of the map can more realistically be appraised. As Keates[484] pointed out: "The question of 'accuracy' in a map is not only a matter of scale, position and measurement in plan and height. The map can only be 'accurate' if all the information is specified, and if in turn this information is passed on to the user. Most modern map series have become much better defined as regards to metrical information: scale, projection, grid, type of survey, etc. are normally indicated in the margin of each sheet. The same sort of approach must be attempted with the other map information, before a real assessment of 'accuracy' can be made".

12e GENERALISATION AND DETAIL

Generalisation in cartography refers to the progressive decrease in the information which can be shown on a map as its scale is reduced. This has a manor effect on the content, appearance and function of a map, larger than intuitive initial impressions would suggest. A reduction in scale from 1:250,000 to 1:1,000,000 means that the same region must be portrayed on 1/16th of the paper area. This in itself would pose no problems if all discrimination remained unimpaired when reduced in size. However, to remain discriminable at the smaller scale, symbols must retain their size and lines their thickness. Cartographic conventions of portrayal cannot be directly transformed in a way commensurate with the scale reduction. Information must therefore be discarded, modified, combined, simplified, exaggerated or even displaced, as part of the process of generalisation. This process must not be arbitrarily or rigidly defined, nor must the generalisation be allowed to change the character of the region portrayed. A jagged coastline must still appear to be so, and a meandering river must still meander at the smaller scale. Logical locational connections between features and physical relationships must not disappear. The network of communications must still link settlements. The complexity of the drainage system and its relation to relief must be conveyed. Many of these points are discussed fully by Keates[120]).

Topfer and Pillewizer[607] demonstrated that, in selecting information from more detailed source material for portrayal on maps at smaller scale, cartographers follow closely and intuitively the radical law of cartographic generalisation. According to this law, the selection of material for a smaller scale map can be expressed mathematically as a function of the density of features on the source material, and the scales of the source material and the derived map. This enables the cartographer to predict the approximate amount of information he can expect to portray on a derived map of any known scale. The principle is widely applicable, by substituting different constraints, for example for point, linear, and area features, in the general formula. Its applicability extends to place names, and to the generalisations of outlines and forms. Its utility is restricted to giving quantitative guidance, indicating how many or what proportion of features in each category should be selected, but leaving the compiler to decide which specific ones should be chosen. Further formulae for achieving regular generalisation in selecting information were presented by Srnka[476] who elaborated the treatment of linear features to include the factor of line length. Morrison[473] described generalisation in terms of set theory, which he used to propose how the classification of symbols should vary to take account of generalisation and map scale. A comparable approach with similar aims but based on information theory was adopted by Sukhov[475], who also derived formulae to assess the consistency of cartographic generalisation. Such formulae, while of practical value, cannot take full account of the more qualitative influences on the practice of generalisation, such as retaining terrain characteristics and showing locational relationships and dependencies. These aspects of generalisation can contribute substantially to the observed differences between aviation maps.

Initially the problem of generalisation on aviation maps was associated with increased aircraft speeds and the resulting need to reduce map scale (Miller[41]). Solutions could be found for high level flight, where operational requirements could be met by mapping major features (Schreiber[25]). Low level requirements introduced the need for detailed information on the map. To some extent this could be reconciled with low speed requirements by providing larger scale mapping suited to operational needs (Wright and Pauley[349]). The advent of high speed low level flight tended to produce problems of generalisation with no satisfactory solution because of conflicting requirements. At low level, small features may be glimpsed but the general shape of large features may not be apparent. Thus for navigation and other tasks many detailed features may be needed on the map. They can be provided only on a large scale map. At high speed there is not time for lengthy perusal of a large scale map in search of detailed features, and the bulky quantities of large scale mapping required to meet such a need would lead to severe handling problems in the cockpit in high speed low level flight. Techniques of generalisation must therefore be used to try and strike an acceptable compromise between map scale and operational requirements.

In dealing with the human factors implications of generalisation in aviation maps, it is useful to follow Keates' distinction between location and meaning. Whether generalistion of location is by selection, combination or simplification, singly or together, principles of form and pattern perception should help to indicate the extent of changes which may be made without destroying perceptual structuring and rendering features unrecognisable. The kinds of evidence needed can be deduced – on the role of redundancy in form discrimination (Rappaport[667]), or the relationship between visual organisation of patterns and their judged complexity (Payne[614]), or the critical factors which determine whether patterns are judged to be the same or different (Sekuler and Abrams[237]) – but the limited evidence available is not sufficiently practical, comprehensive, clear or authoritative to be applied to map generalisation, and more specific evidence for this purpose should be obtained, mainly from laboratory studies. Examples of questions are the following. How much simplification can be tolerated if lines at different scales must still appear equally jagged? Which detailed parts of the outline of a filled area must be retained at a smaller scale to ensure that the shape is still recognised? What is the best method for showing on a small scale map that a region contains many small features (e.g. lakes, streams, copses) where principles of generalisation would suggest that it contains a few large features, or none? How far can generalisation employ displacement without leading the user to question the accuracy of the whole map? Is it valid, in considering which features may be combined, to presume that features in different elements (e.g. land and water) must not be combined, but features within the same element (e.g. wooded and unwooded parts of the land surface) may be?

Generalisation of meaning poses different problems, one of which is the obliteration of operationally useful distinctions within a category or subcategory. This has two aspects. One concerns the portrayal of hitherto differentiated features in the same way: all roads may be alike for example. Another concerns the selective portrayal of features in a category: all roads are not shown, for example. Sometimes a separate coding may imply the presence of features, as when town fill implies that there are roads which are not shown. Often on small scale maps, a selection must be made: all roads cannot be shown if they are numerous because they would lead to excessive clutter and give undue emphasis to roads as an information category, but it is still desirable to distinguish on small scale maps between a region with many roads and a region with few, even though in both cases few can actually be portrayed. The roads selected for retention on the small scale aviation map may not be chosen because of their operational significance, which would depend on factors such as their visibility from the air and their strategic importance, but because of their importance on the ground according to a road transport classification.

In applying generalisation to aviation maps, it is vital that the map compiler has a detailed understanding of how the map will be used and what information will be needed, since the specialist requirements of aviation may entail some modification of the normal processes of generalisation. In particular, the principles of generalisation for an aviation map should be derived from source material, and not from another map which is itself a generalisation (Keates[120]). Also excessive reliance on photographic source material may fail to provide an adequate cartographic basis for forming categories and subcategories (Keates[484]), and for grouping these in the most efficient way for aviation purposes.

The ways in which generalisation limits map detail, and the problems in formulating principles of generalisation for maps with worldwide or very extensive coverage, require far more attention in relation to aviation maps than they have received. The perceptual implications of generalisation are not fully understood, and methods of retaining the correct impression of the general character of terrain at various scales are often inadequate. The selection of information for inclusion on the map often follows cartographic practices which have proved their worth in other contexts, but which may fail to meet aviation needs. The vast conglomeration of theoretical studies on principles of pattern perception has seldom dealt with patterns where all the material is meaningful as on a topographical map and so it cannot furnish guidance on how the aims of generalisation may best be achieved perceptually.

12f MAP SCALE

Map scale is the most important single source of differences between aviation maps. The choice of the correct scale to serve operational needs is the main determinant of the map's efficiency, since it limits the information which can appear on the map. Aviation maps may range in scale from 1:4,000,000 to 1:50,000, and occasionally outside this range. The commonest scales are 1:1,000,000, 1:500,000 and 1:250,000. It is beyond current resources to achieve worldwide coverage for aviation purposes at a larger scale than 1:250,000, and for some geographical regions reliable data to compile accurate maps at larger scales are not available.

Although traditional map scales collectively provide a reasonable set of maps to serve most aviation purposes, developments in display technology, and the comparison of mapping with material generated from radar, infra-red, and other sensors, may require the map to be adapted to the sensed data. This constraint applies to scale as to other factors. The scale of a map for combined radar map matching displays must be that of the radar display, and the map must usually be reduced or expanded in order to match the radar. In a projected map display the scale of the map image is a function of the photographic reduction and optical magnification factors. In the future, therefore, the scales of aviation maps may be expected to become more flexible and variable. It follows that the scale of maps in any form other than paper will tend to be less self-evident and familiar. Computer mapping permits such flexibility, but its full implications in terms of training and misinterpretations of scale are not yet known.

Lichte et al.[56] identified map scale as a neglected factor in relation to the efficiency of reading aviation maps. Faced with the problems of interpreting radar displays in relation to map, Lichte[58] examined the effects of map scale and amount of information on target identification. For identifying targets from photographs, larger scales were better, and greater visual emphasis on cultural features on the map was advocated (Lichte et al.[57]). Their finding that level of information on the map had no significant effect on performance seemed to warrant further study. A large scale map was suggested for radar interpretation, and a smaller scale map for navigation and orientation (Lichte[59]).

The maintenance of orientation was the primary concern of a series of studies by McGrath and his colleagues in which pilots' performance of simulated flight tasks was measured. Whereas according to Lichte map scale was important but the amount of information on the map was unimportant in target identification and town shape recognition tasks, according to McGrath et al.[132] a change of map scale had no significant effect on performance of a low altitude orientation task as long as the information content of the map was held constant, and only when a change of scale was combined with a change in information content were there significant effects on performance, better performance being associated with more information on the map. As a result of this finding, they hypothesised that it should be possible to reduce map scale without impairing orientation performance, and tested this hypothesis in the following year (McGrath et al.[319]). The results refuted the hypothesis, but were complex, being dependent on the route flown. It was suggested that for the different conditions of flight associated with different routes, pilots might have adopted different orientation strategies. Heap[124] also considered the effects of map scale on the maintenance of orientation, in his discussion of visual factors in aircraft navigation.

In a study of low altitude navigation with Army tactical maps, Grey et al.[351] measured direction estimation using maps of different scale, but the advantage of the 1:100,000 map over the 1:250,000 could have been a function of the different frame of reference associated with grid line frequency. When the task for Army aviators was position location, and the scales compared were 1:250,000 and 1:25,000, error magnitudes were approximately a linear function of scale, and it was concluded that while a modified 1:250,000 scale map would suffice for enroute tactical navigation over considerable distances, an intermediate scale, perhaps 1:100,000, would be needed for tactical manoeuvring in a target area (Edmonds and Wright[308]). For Army navigation at low levels, particularly over unfamiliar terrain, Wright and Pauley[349] believed that automatic dead reckoning in some form was necessary, and that the cartographic problems, coupled with human limitations in maintaining orientation, were insuperable without such automated assistance.

A foretaste of some future problems with map scale was apparent in McKechnie's[218] investigation of alternative maps on which targets to be found on sidescan radar imagery were marked. Neither of the maps examined was at the same scale as the radar imagery. Although both maps produced spectacular improvements in finding designated targets and in minimising false positive responses, the importance of the factor of scale, and particularly of similarity of scale between map and collateral material, could not be established. The study of pattern recognition at different scales, at different orientations, and with changes in visual emphasis lends itself to controlled experimental methods to identify the relevant perceptual variables and their relative importance, but has not been pursued in ways which are pertinent to

map scale. It would be expected that the facility to recognise patterns at a different scale or in unfamiliar guise would improve with appropriate training, but this has not been demonstrated in ways which give practical guidance for training map users.

In transforming scale, it is necessary to consider whether aviation maps require specific principles of selection (Topfer and Pillewizer[607]). Rather than portray on smaller scale maps a proportion of features exemplifying a specific cartographic category, it might be operationally desirable and less potentially misleading to retain all examples of certain features (such as railways and airfields) and discharge others completely. A firm conclusion on this point cannot be reached on existing evidence, but though portraying a proportion of features is good cartographic practice in other contexts it may be highly misleading and potentially dangerous if the categories of features most readily visible from the air may or may not be mapped in individual instances. On the other hand, the principle of portraying all examples could be taken too far and lead to excessive clutter and difficulties in portrayal. It is important to decide whether all examples of a cartographic category, or only a selected specified proportion of them, need to be portrayed, when job analysis is being used to determine operational needs and the quantity of information which must be provided, and hence the scale which will be most suitable. This is the logical sequence to follow in determining the scale of an aviation map. Although scale is thought of primarily as determining the quantity and accuracy of mapped information, it also affects content, by reducing subcategories, and by modifying the meaning of certain codings: Bartz[99] noted the role of typefaces as a scale indicator in this connection. Very small scale maps illustrate gross reductions in cartographic information categories.

A final note must be appended on the secondary meaning of the concept of map scale in cartography, related to the primary one of the distance between any two points on the map as a proportion of the distance between the same two points on level ground. A map scale may also be a line, forming part of the map legend, intended to provide a measure for reading distances on the map in terms of distances on the ground. In designing this scale – its length, anchor points, intermediate marks, line thickness and weight, and annotations – standard recommendations for the design of linear scales given in handbooks of human engineering should be followed, modified as appropriate to take account of such factors as cockpit vibration, level and colour of illumination, viewing distance, minimum eyesight standards, and the design of measurement tools used with the scale.

12g THE PREFERENCES OF THE USER

Whether the preferences of the user account for major differences between aviation maps depends on a combination of three factors:

1. How much the user has been consulted.
2. How closely his expressed wishes agree with his true needs.
3. How well informed the cartographer is about map usage.

When the user is asked for his views about an aviation map, he usually considers it for the tasks which he can envisage in a postulated operational role. He tends to compare it with other maps he is familiar with. He also concentrates on the tasks he has done or knows of, and often has insufficient appreciation of future operational roles to evaluate maps in relation to them. The user's frame of reference for evaluation and his time scale can therefore be different from those of the investigator. The former is preoccupied with his everyday requirements whereas the latter may be trying to compile a specification for a map which will not come into service for several years. The researcher may be concerned with roles or missions which do not yet exist, or with map reading tasks for which there is a future requirement but no current one. In these circumstances questioning of prospective map users can lead to misunderstandings, and differences between maps may reflect both the extent of the users' influence and how informed their comments were.

It is therefore essential that both researcher and user know exactly why the user is being consulted when his views are obtained. Otherwise his stated preferences may be based on false premises. It is also essential that the methods of consultation must be appropriate for the objectives. A user may be asked for his comments on the specific content and portrayal of an experimental map, or he may be invited to speculate on cartographic data that would be useful to him if provided: in either case he must know in detail the kind of mission envisaged, his role, his tasks, the other navigation aids he would have, and the operationally acceptable standards of performance. If this is not made clear, different users may make different assumptions and apparently hold more diverse opinions than they do. There must also be a distinction between absolute requirements and preferred alternatives.

Despite these caveats, it is desirable always to consult the user. He has different knowledge and experience and a different frame of reference. Ultimately the value of the map depends on what the user does with it. The user can envisage how he would use the map, and can convey this to the cartographer. If this does not accord with the cartographer's intentions or with operational requirements, any discrepancies must be resolved, in the interests of operational efficiency. The user can identify difficulties in the proposed usage, and perhaps suggest extensions to anticipated uses. Consultation has value in its own right, giving the user the satisfaction of stating his preferences, although this can become counter-productive unless his views are seen to be heeded. This does not imply he must get everything he wants, but simply that his influence on certain attributes of the final map can be traced. Such consultation can ultimately bring the benefit of greater willingness on the part of the user to accept and try to succeed

with a product he has helped to specify. Maps which have been influenced by users' expressed preferences may be more operationally efficient, more practical, more colourful, and less innovative than the cartographer's unsupplemented efforts. Thus differences between map series may be a reflection of the nature and extent of user consultation and of the inclusion of the users' stated requirements in the map.

The user states what he wants to see on the map. What he needs is determined by job analysis, in relation to operational requirements, user's capabilities, and cartographic practice, a criterion being success or efficiency in task performance. Wants and needs may or may not coincide. The user may have insight into his performance and prefer what is most efficient, but it is quite common for stated preferences to clash with operational needs. McKechnie[747] showed in his comparisons that for successfully flying a prescribed flight path a photostrip in a display was superior to a moving map in the display, which was in turn superior to a hand-held map, but pilots wanted the hand-held maps. McGrath and Borden[121] also found discrepancies between user preference for maps and the best maps judged on the basis of navigation performance data. Hill[516] tested orthophotomaps under field conditions, and although there were scarcely any performance differences subjects preferred the familiar line map. Objective and subjective evidence need not coincide – if they always did, it would be pointless to collect both. Users act on what they believe to be the case, that is according to their expressed subjective opinion. If this conflicts with objective evidence, they usually are unaware of this, and often find it difficult to believe. Since early investigations (Murray[28]; Schreiber[25]), it has been common practice to obtain both subjective and objective data in map evaluations.

Although there may be discrepancies, the subjective and objective data can be mutually confirming when they are in substantial agreement. Murrell's[131] highly detailed study of users' selection of cartograhic information for small designated map regions, which included assignments of assessed operational importance to each selected cartographic feature, gave very similar results to an experimental map compiled from an air survey of the region, and Murrell interpreted this as validating both techniques. Some cartographic techniques depend on subjective assessments, and therefore have to include subjective judgements in their usage and validation. In selecting a sequence of shadings or tints, the criterion is subjective equality of intervals, and it is irrelevant to adopt an objective method if it does not produce subjective equivalence (Jenks and Knos[94]).

It is possible to obtain a comprehensive evaluation of an aviation map from users' preferences (Lakin[633, 340]), although such an evaluation retains the limitations associated with the method, and its objective validity cannot be presumed. If there is a consensus of adverse opinion among users, which is known to come from independent sources so that it could not be a collusive group view agreed after discussion, this indicates that the map is unacceptable. Even if it is efficient, users who find it unacceptable may be unwilling to use it, or may fail to use it to best advantage. Hopkin[70] discussed some of the reasons for the unfavourable comment on the Joint Operations Graphic in terms of display principles and human factors data, but noted that the application of human factors data, even if proved to be valid, would not be a substitute for user opinion which provided a different kind of evidence. If there is no operational penalty according to objective measures, providing users with what they want can be advantageous in enlisting their effort and collaboration. Users not only like colour as a coding because it is attractive (Sanders[622]) but also have views on the attractiveness of alternative cartographic techniques.

Maps also differ because cartographers vary in their knowledge of how they are used. The JANAIR Symposia (McGrath[68, 69]) sought to inform users and cartographers of each others' problems, and in particular to ensure that users' future needs were defined so that there would be time for cartographers to meet them. This is a general problem for cartography, not confined to aviation maps, and Harris [727] summarised two conferences which sought to compile and integrate users' requirements. Harris saw automated cartography as the future solution to many user requirements, and this is also seen as an aid to military mapping, particularly in meeting tactical requirements for rapid mapping (Schaubel[153]).

It is tempting but wrong to assume that once the cartographer has a full understanding of users' needs he will be able to produce maps to meet them. New needs may produce cartographic problems for which a solution has to be found, or for which none can be found. The users' preferences may rest on suppositions which are wrong, or may lead to sources of confusion which the user cannot predict but the cartographer can. The user may know that for radar map matching he needs a map pattern which he can compare with the radar without error, but he may not know what kind of pattern would be best, or even what kinds of pattern are technically feasible. The preferences of the user may not always be stated so specifically that they can be implemented without modification or interpretation by the cartographer, and the user cannot be assumed to have a comprehensive knowledge of mapping when he expresses his needs. Differences among cartographers in their interpretations of users' stated preferences can lead to differences between aviation maps.

12h THE INFORMATION CONTENT OF COLLATERAL OR SUPERIMPOSED DISPLAYS

If a map has to be used with collateral displays, this may influence its content and appearance greatly, sometimes to the extent of requiring special mapping which differs radically from other aviation maps. The map may be used for briefing or planning how to use collateral or superimposed information, may be used in conjunction with it as it is generated, or may be used afterwards to interpret it. Whatever use the map is intended to have, its value depends on its visual affinity with the other sources of information. This implies a requirement to predict the features which will appear on the collateral or superimposed displays, and whether these features will be sufficient to enable the displays to be related

to the map. If they are insufficient, further cartographic information may have to be added until sufficient visual relationship between the display and the map has been established. Similar considerations also apply to the method of portrayal of information on the map which must be compatible with the display and have sufficient visual resemblance to demonstrate correspondence in patterns. The format of any additional cartographic information must relate to the collateral display; otherwise the compilation effort will go unrewarded.

Any form of collateral or superimposed display, such as radar map-matching (Braid[344]), or sideways looking radar (McKechnie[218]), illustrates these principles. Guidance on the extent to which conventional mapping may be unsatisfactory may be gleaned from relating operational requirements to factors such as redundancy (Rappaport[667]), pattern complexity (Bush et al.[217]), and surface texture (Gibson[81]). The influence of the collateral or superimposed material on mapping will also depend on the envisaged form of the mapping, and particularly on whether it is direct view, projected or kinescopic (McGrath[433]). The feasibility of electronically generated mapping introduces further options for relating maps to other material (McGrath[160]), while increasing the potential sources of differences between aviation maps.

The criteria for determining the information content of electronically generated maps can be quite different from those of conventional maps, since they may depend on programmed instructions rather than on visual appearance, and hence have the potential for drastically changing the principles of selection in relation to map scale. The scale itself may be manipulated by software instructions. If the collateral or superimposed material is also digitised or expressed in computer terms, as with digitised infra-red linescan displays, the possibility of computer comparisons and correlations can be contemplated, instead of visual ones. The consequences for visual judgement are complex, and the role of man in verifying the validity of comparisons may be difficult to achieve. One major problem is that a significant mathematical relationship between patterns may or may not appear as a visual relationship to an observer. Notions of sameness or equivalence in pattern perception depend on whether the man or machine is correlating the patterns. Whether it would be better for operational purposes to rely on mathematical correlations between digitised map information and collateral material or on visual judgements of analogue or digitised information, is a matter of speculation. Optimum performance probably occurs if both are employed and each can be used to check the plausibility of the other. While the feasibility of such technological developments can be foreseen, the human factors evidence which will be needed to judge how they may best be used for operational purposes has yet to be gathered.

12i DISPLAY TECHNIQUES

A variety of display techniques is available for presenting cartographic information in aircraft cockpits. In an era of rapid technological advances, many new display techniques can be examined to see if they could be applied to the cockpit. In future cockpits, greater use will almost certainly be made of the cathode ray tube as an information display. McGrath[160] compiled a list of map displays, and noted further technical possibilities not yet in production. Most of these are discussed in Chapter 11c.

On the whole, new display developments belie the tag that necessity is the mother of invention. Far from fulfilling a long-felt need, they usually have to be evaluated to see what they could possibly be used for. A new display is not normally a response to a future operational requirement; rather the operational requirement has to be fitted to the current state of the art in display technology. In general, technological advances are not modified to fit existing maps; it is the maps that have to be modified to fit the technology, which for cartography and for human factors may be a lengthy and ultimately unsatisfactory process. Just because an acceptable solution to a technological problem can be found, it does not follow that there must be satisfactory solutions to all the cartographic and human factors problems which it poses. Advances in displays have not usually been made in response to cartographic requirements or human factors considerations, nor even in response to operational requirements. There is therefore no justification whatever for taking it as axiomatic that new display aids in the cockpit must lead to better maps, be compatible with human abilities or improve task performance and efficiency. If these benefits do ultimately accrue from a new aid, they are likely to owe as much to the competence and ingenuity of supporting cartographic effort and to the successful solution of associated human factors problems, as to the aid itself.

Any new navigation principle has normally to be adapted and developed for human use. A projected moving map display is an encumbrance unless the man can read the map. Radar map matching is pointless unless the man can see something he can match the radar map with. Continuously generated material is of no use if it moves so quickly that the man can only see a blur. If the man must wear image intensification goggles but cannot read any map through them, then his operational role, or the way he fulfils it, may have to be changed. This is not to decry all advances in display technology, many of which have been highly beneficial in the past. It is vital to recognise, however, that these benefits are not intrinsic and automatic but have to be worked for; where they involve cartography or human factors, or both, they generally pose difficult problems which have to be solved as a condition for making use of the new display. There is always some tendency, in evaluating something new, to concentrate on demonstrating its envisaged merits, and to underplay the operational implications of its flaws.

Display techniques are therefore proving to be a major source of differences between aviation maps in the cockpit. Even if roles are similar, maps may have to be different to meet display requirements. Paper maps are generally not suitable without modification for projected displays, for superimposition, for use as collateral material, for viewing

through goggles, or for presentation on videotape, on a cathode ray tube, or as a television display. The more display technology advances, the greater will be the need to introduce specific cartographic modifications to obtain suitable maps for each one. The more constraints the display technology imposes, the less applicable the lore of cartography becomes to solve the problems which arise. Cartographic language, symbology, information density, format and content may all have to be questioned, to the extent that it may become debatable whether the final product can be described as a map. Display technology affects not only the content and appearance of the map, and what can be read on it, but also what it can be used for: what can be looked at again, how far ahead the map can be used, whether annotation is possible, the usage of plotting aids, etc. New tools, measures, annotation methods, and aids may have to be devised, not to extend the functions of the map in its new form, but to keep the functions it formerly had. Such factors, of greater operational importance, need to be considered when cartographic display techniques are evaluated.

CHAPTER 13

INDIVIDUAL DIFFERENCES

13a SELECTION AND TRAINING OF CARTOGRAPHERS

Individuals differ in a very large number of ways, some of which are relevant to cartography. It can be assumed that everyone would not be equally good as a cartographer. If particular skills or attributes can be identified as essential or desirable in the good cartographer, tests of the possession of these skills or attributes, or of the potential to acquire them, can be used to select people who could become cartographers. Appropriate training can then turn this potential into reality by engendering skills, knowledge, experience, techniques, standards of performance and professional ethos.

Effective selection and training procedures presuppose that the requirements for the job can be defined and that the extent to which they are met can be measured. If the hallmarks of a good cartographer can be stated, they provide the means to verify the efficacy of cartographic selection and training procedures generally, and for individuals. If the hallmarks are unknown or speculative, then it becomes necessary to deduce what they might be, by analysing the principles and practices of cartography and relating these to measurable individual differences in pertinent human attributes. Judgements are required on how far the relevant attributes depend on innate characteristics and how far they can be learned – on whether a good cartographer is born or made. Selection methods seek to discard all those who, for whatever reason, are incapable of becoming proficient cartographers.

All the attributes of a good cartographer cannot currently be listed, and for various reasons some may be changing. It is therefore not immediately obvious how cartographers should be selected or how they should be trained. There is even disagreement on what cartography is: Ratajski[466] noted that it could be defined as a science or as a skill, and Keates[120] cites a definition of cartography as the "art, science, and technology of making maps . . .". Cartography may be construed as embracing every aspect of mapping, but in this section (and generally throughout this text) its meaning is confined to the handling and presentation of data, as distinct from data collection. Cartography as a discipline has tended to emphasise the provision of information rather than its practical usage, and to presume that if information can be presented and discriminated it can also be used. On a strict interpretation, an understanding of how maps are actually used, as distinct from how they could in theory be used, might not be a necessary aspect of a cartographer's training, though many would contend that such an understanding is indispensable.

A text, such as that of Keates[120] on the theory and practice of cartography, can be used as a basis for stating what the cartographer's job is and hence for deducing the attributes which would be advantageous in a cartographer, provided that this deductive process is extended to include any further cartographic functions which the text specifically omits, such as projection systems in the case of Keates. These attributes are not expressed in cartographic terms but in human factors terms.

The following is an example of a list of factors of potential relevance to selection, compiled deductively. For all these factors, standard tests or measurement tasks exist.

(1) Cartography is primarily concerned with visual perception. Potentially relevant attributes amenable to testing include:

colour vision; visual acuity; visual memory; comprehension of shapes; pattern perception.

Long term eyesight changes may need to be predicted as part of a selection procedure for cartographers, to ensure that deteriorating eyesight is not an occupational health hazard.

(2) Cartography is concerned with communication, visual and verbal. Potentially relevant attributes amenable to testing include:

verbal reasoning; linguistic aptitude; logical thinking; vocabulary.

(3) Cartography is concerned with painstaking and high skilled scribing work, demanding consistently high levels of performance. Potentially relevant attributes amenable to testing include:

manual dexterity; mechanical ability; motivational strength; obsessionalism; clerical ability.

(4) Cartography requires the understanding and recall of complex concepts and processes. Potentially relevant attributes amenable to testing include:

general intelligence; abstract reasoning; spatial reasoning; cognitive functioning.

(5) Cartography requires forethought, planning, and good management. Potentially relevant attributes amenable to testing include:

Managerial ability; organising ability; creative thinking.

(6) Cartography requires numeracy, quantitative thought, and an understanding of digital principles. Potentially relevant attributes amenable to testing include:

numerical ability; nonverbal intelligence; computer programing ability.

The above list is not exhaustive, is tentative and is hypothetical rather than proved. If particular cartographic tasks entail interdisciplinary work and an understanding of the jobs of others, certain social skills may also be required in the cartographer. Some personality factors, such as patience or persistence, may also be important enough to be included in a selection procedure. The above list illustrates the logical thinking of job attributes to psychological dimensions which can be measured quantitatively by existing tests or standard tasks. This linking is a preliminary stage in defining relevant factors for a testing programme intended to assess which of the identified factors have predictive validity in selecting cartographers.

A comparable process can be followed in relation to the training of cartographers, to establish what knowledge they need to acquire. From descriptions of cartographic processes, from the observation and measurement of cartographers at work, and from task analyses, the knowledge which needs to be instilled during training can be derived. Potentially relevant knowledge includes the following:

(1) Principles of visual perception, discrimination, structuring and legibility.
(2) Coding, symbology and other logical principles for communication.
(3) Principles for the display, processing, understanding and use of information.
(4) Typography.
(5) Principles of good design.
(6) Data collection methods, and their relative merits and disadvantages.
(7) Principles of geography and topography.
(8) Geographical map content.
(9) Cartographic conventions and standards, for categorisation, presentation and generalisation.
(10) Printing and ink technology, photographic and non-photographic cartographic methods, and associated chemical and physical processes.
(11) The organisation of map compilation and production.
(12) Computer procedures in map compilation and production, and in handling cartographic data.
(13) Map projections and transformation principles.
(14) Scribing and draughtsmanship.
(15) Definition of the map user's requirements.
(16) Skills and knowledge of the map user.

The above list is not intended to be fully comprehensive, and all the items in it are not of equal importance: on some topics, knowledge in depth is essential, whereas on others a smattering of knowledge may suffice. Nor is the previous list, compiled for selection purposes, closely related to this list: the former list is of postulated desirable and measurable attributes in the cartographer and presumes some individual differences, whereas the latter list is of topics on which the cartographer should acquire some factual knowledge during training. Both kinds of list can be compiled from an understanding of the principles of cartography, coupled with an examination of what the cartographer actually does.

Training is not only a matter of gaining knowledge but also of learning techniques and acquiring skills. A selection procedure is deficient if it fails to select those who have the capacity to develop cartographic skills. It should reject those who are clumsy or careless, or too readily distracted, or indifferent to professional standards. The aim is to choose those with the abilities and temperament to become cartographers, and train them to achieve what they are capable of.

Selection and training methods have to be validated. For selection, validation implies a demonstration that those selected become better cartographers than those rejected would have become, and also that, among those selected, the best when selected tend ultimately to become the best cartographers. For training, validation implies that the relevance and the worth of the contents of training and of the techniques and skills acquired can be demonstrated in terms of the quality of the cartographic product or of cartographic understanding. Ideally, no major omission from training can be made without incurring a relevant decrement which can be pointed to, and no major addition to training can be made which would result in a substantial cartographic improvement.

Methods of validation have to employ a touchstone independent of what is being validated – a separate index of the quality of cartographic achievement. It may depend on subsequent career, on independent assessments of the

individual's cartographic work, on professional reputation, on instructor's assessments, on standard tests of attainment, on subsequent formalised assessment procedures, or, most commonly, on a combination of some of these factors. Gross deficiencies in selection or training methods may emerge at a relatively early stage during validation, for example if the predictive value of selection is low or non-existent, or if during training irrelevant skills are acquired, but essential skills are conspicuously absent. Thereafter, the refinement and continued development of procedures for validating the selection and training of cartographers is a matter of progressively finer tuning of them in relation to progressively less obvious deficiencies in the cartographers they produce.

Additionally, allowance must be made for changes in the nature of cartography. These should be mirrored in selection and training procedures which must be flexible enough to meet changing needs, by adding or omitting aspects of selection or training or by weighting aspects differently in accordance with changing priorities. The increased emphasis on photography and on computers in cartography requires corresponding changes in selection and training, to ensure that the cartographers being selected now are not overburdened with knowledge and skills which once were needed but are scarcely used any more. Selection and training procedures must always look to the future.

13b SKILLS AND ABILITIES OF CARTOGRAPHERS

In principle, because many factors can be postulated as relevant in the selection and training of cartographers, the skills and abilities of cartographers may be complex and numerous. The implication is not that few people could ever acquire the requisite skills and abilities, but rather that the process of becoming a cartographer may be protracted because there is a lot to learn, and that a cartographer's skills may continue to improve gradually for a long time after the end of his training. Cartographic skills also seem diverse. A corollary of their great diversity is that no individual cartographer is likely to possess them all in equal measure; therefore each might be well advised to specialise in those aspects of cartography demanding the particular skills and abilities which, as an individual, he possesses. The ordered and logical thought processing needed in some computerised and mathematical aspects of the subject may be hard to reconcile with the more intuitive thought processing needed in certain aspects of compilation and design.

The skills and abilities of cartographers are of a different order from the skills and abilities of map users. The cartographer employs a high level of skill to achieve an effect of simple and immediate meaningfulness of the map for all users. Most users of aviation maps do not expect to devote a great deal of time and effot to learn how to use them. Subtle distinctions of meaning in symbols, or subtle indications of quality of information, may often remain unnoticed or may arouse complaints among users if they have to be learned, since most users naively expect any feature with a physical location on the earth's surface to appear exactly and correctly on the map of that surface. Therefore the cartographer cannot assume that the user has insight into his problems or sympathy for them.

In his pursuit of a clear, practical and pleasing map appearance, the cartographer must use his skill to minimise the consequence noted by Wright[16], that the more he succeeds in his purpose the more he may convey spurious impressions of accuracy on the map. He must also remember that after a map has been made it may no longer be possible to establish its quality. In coping with generalisation, and in trying to retain the essential character of a region on a smaller scale map (a rugged coastline for example), the cartographer may introduce conjectural amplification, where the need to achieve general realism has superceded the need to portray only the accurate truth. For some purposes this is acceptable; for most aviation uses it is not. Skill is needed to retain the correct general cartographic impression within the strict confines of features which are all individually correct. In striving after visual harmony on the map, because an ugly map may lead to a loss of confidence in it, the cartographer may be reluctant to acknowledge that for some aviation maps it may be an advantage to generate some loss of confidence, and a means of achieving this should not necessarily be despised. Skill is required to judge how the balance should be struck.

In addition to cartographic skill, Boggs[482], following the ideas of Wright[16], suggested painstaking accuracy and scientific integrity as further characteristics of the good cartographer. He was aware that the selective processes in compilation and generalisation could inadvertently or wilfully distort the truth, because users tend to accept the map uncritically. The importance of compilation was illustrated by Balasubramànyan[254], who showed, in considering the map as a medium for conveying information, that the compiler's ideas were dominant in influencing the content and format of the map. He suggested that the compiler would benefit from a greater knowledge of the principles of design. This theme was developed by others who considered that cartographic training overemphasised the technical details of map construction to the neglect of an understanding of how to communicate information successfully using a graphic language. As a result, an undesirable division of skills could develop between the cartographer dealing with content and the designer dealing with presentation, but these functions have to be integrated, and both should be part of cartography. Ratajski[466] was also concerned with ways in which the effectiveness of transmitting information by means of a map could be promoted by cartographic skills. Carmichael[647] noted that excessive emphasis on map construction, and stereotyped and rigid construction techniques, could lead to dull maps made by uninspired cartographers, like the many computer-drawn graphics arising from the 'new wave' of auto-cartography. Working to a rigid specification could take away much of the challenge and interest of map-making for the cartographer.

Some of the advice on how cartographic skill is best applied is contradictory. Whereas Dornbach[748] favoured concentration by the cartographer on specific symbols, Heath[147] believed that principles of visual design, derived from symbols in isolation, may not remain valid amidst the complex interacting visual context of the map. Kolacny[463] held

that the production and use of the map should not be studied separately. Although the cartographer's traditional skill lay in employing techniques for transforming detailed information about the real world into map form, his skill must extend to identifying the map user's tasks and to designing the map to fulfil the needs of users as efficiently as possible. This approach implies that cartographic products cannot be optimum unless the cartographer is skilled at understanding the user's needs and at designing the map accordingly. Such a point of view extends far beyond the traditional expertise of the cartographer. So does the need to understand the principles and practice of automation in cartography. Yet each requires at least some cartographers to possess the relevant skills.

A further practical skill of the aviation cartographer is the reconciliation of conflicting user requirements. This may be achieved in two stages, both of which rely on his professional knowledge. Firstly, when many users have a large number of requirements, all of which cannot possibly be met by a single map, the cartographer must identify the technical options available and establish feasible ways of reconciling the requirements. Secondly, having established and agreed the constraints within which the specification for the map will be compiled, and having clarified the group of functions which each map is intended to fulfil, he must then design each map series for the multi-function role which he has helped to specify. Furthermore, he must demonstrate that his advice was correct by ensuring, in the details of his design, that the functions can all be fulfilled and reconciled within the map. Such a role makes demands on the cartographer's knowledge, skill and judgement, and if his expertise is insufficient then the operational consequences can be serious. Some of these processes were described by Bennet et al.[114] in relation to the Joint Operations Graphic.

The operational dependence on the cartographer's ability to select the most appropriate features for portrayal in relation to a specific type of mission was illustrated by McGrath and Borden's[121] analytical study of visual checkpoints identified on film and on a map. This method was used to establish its validity as a design criterion for aviation maps, but it could also be used to assess the cartographer's skill at predicting and meeting certain operational requirements.

A group of cartographic skills relates to the assessment and measurement of cartographic data. Techniques for selection and generalisation are included in this group, where increasing skill may be demonstrated by greater subtlety and complexity in the factors having some influence on the choice, content and format of data presented. Other techniques concern the variables affecting relationships and levels of association. These determine how similar or different maps appear to be to each other, and whether the relationships selected for portrayal are intelligible to the user and reflect corresponding geographical relationships. Not only is a knowledge of the techniques essential, but also a knowledge of experimental design so that the efficiency of the techniques can be measured without recourse to unwieldy and inconclusive methodology, such as used by McCarty and Salisbury[517] and others.

More ambitiously, the cartographer's skills could conceivably extend to predicting the kinds of error which the user will make, or which tend to be inherent in some cartographic processes, and compensating for them in some way in the map design. This may not be totally impractical. For example, suppose that an accurate measure of the length of a linear feature on the map is required. It is known that such cartographic processes as scale changes, selection and generalisation have relatively predictable effects on the accuracy of line measurement, given information on the nature of the line, on the measurement tools, on the general accuracy of the map, and on the proposed measurement technique. The line length will tend to be under-estimated in relation to the size of the line feature on the ground, and methods of correcting these systematic errors have been proposed (Maling[745]). Skill is being exercised at a very high level if the cartographer can compensate in the map design for predictable sources of deficiencies and inaccuracies in his own cartographic techniques. Phillips et al.[749] illustrate an example of error in the judgement of relative distance caused by the positioning of intermediate features; if such judgements were the primary task, deliberate distortions in positioning of features could be justified if no serious penalties were incurred for other tasks.

Although cartographic skills are complex, particularly with the modern expansion of mapping techniques, there is no reason why they should not be identified by standard methods, collated and assessed. Measurements can then be formulated of cartographic skills and abilities. These measurements could be used to obtain proficiency scores for individual cartographers, to reveal their strengths and weaknesses, to suggest the kind of cartographic work that would suit their talents best, and to propose further training. The result should be more satisfied as well as more efficient cartographers, for whom there would be objective evidence of their professional competence.

13c SELECTION AND TRAINING OF USERS OF AVIATION MAPS

Users of aviation maps are not selected primarily for their skill in map reading. For aircrew, and for other concerned with the usage as distinct from the production of aviation maps, maps are one of many sources of information, and map reading is one of many tasks. In most operational roles, only part of the time is spent in map reading. Correct and successful map reading may be of crucial importance, in the sense that the success of the mission depends on it, but the same could be claimed for many other tasks. Therefore, although map reading ability may be included in certain selection procedures, a lack of facility in map reading is unlikely to be a sole and sufficient reason for discarding aircrew candidates who are otherwise acceptable. As a result, sometimes aircrew are selected who cannot, in fact, read maps well.

One school of contemporary cartographic thinking has tended to lean towards universal map usage. This places much emphasis on making maps legible, clear, unambiguous, and self evident in their meaning to all users. If some users make repeated mistakes in interpreting a map, or seem unable to learn how to use it, this has been construed as a failure

in cartographic design, and not in the user. This approach rests to some extent on the belief, not uncommon in cartography, that it is possible to train a person to become reasonably proficient in map reading simply by indicating the geometrical principles upon which the map is based, e.g. map scale, vertical elevation interval, projection. To produce a map which is in principle intelligible and unambiguous, given adequate knowledge, skill and training in the user, seems an ambitious enough aim; but to produce a map which is immediately intelligible and unambiguous to all users, even with a minimum of knowledge, skill and training, seems an aim which is overambitious to the point of becoming unattainable. Yet such is the aim of much cartography, which seeks universal usage of its products. This thinking, with its associated standards, has greatly influenced the design of aviation maps, more particularly because of the wide range of users of world-wide map series.

For many tasks in the air, it is accepted that a long period of training and familiarisation will be necessary before the requisite skills and knowledge can be acquired, but less so with maps, although it should be possible to insist on a higher level of relevant attainment and experience among map users. It does not seem reasonable to expect that learning to use maps, which are generally the most complex source of information in the cockpit, should require a long period of training and familiarisation, but this is not a principle which has always been followed. In striving to make the meaning of the map self-evident, the cartographer may have sacrificed too much in terms of subtlety. Codings chosen to be simple, self-evident and clear may not be the most appropriate for deep meanings, fine distinctions, or intricate interactions.

It therefore tends to be taken for granted that everyone can learn to read an aviation map, because that is a principle underlying its design. If everyone can read it, there is no need for a selection procedure for users, and if anyone fails to read it, this failure can be ascribed to the map and not to the user or his training. These presumptions warrant critical re-examination.

A corollary is that little is known about how map users should be selected, because it has not been considered desirable to select them. If selection of aircrew on the basis of map reading abilities is introduced, the standard methods for developing a selection procedure could be followed, namely descriptions of the user's map reading tasks, deduction of measurable relevant attributes, validation of these against an independent criterion of success in map reading, and progressive refinement and adjustment of the measures in accordance with continued validation. The presumption of the universality of some map reading ability should be put to the test, and the possibility faced that some potential aircrew may lack fundamental attributes important in map reading. Although map reading can improve with knowledge and experience, and in some individuals improves greatly, evidence is lacking on whether this improvement is sufficient for every individual to meet operational requirements in map reading, or whether every individual can acquire the ability to read a map when he has been selected according to attributes which have no necessary relevance to it.

The common observation in flying training that aircrew become more proficient at map reading with experience suggests that some form of perceptual learning may be taking place. On the other hand, the improvement may be due to learning of the more routine mechanical aspects of the task rather than a development of perceptual skills. Unfortunately the process is such that aircrew find it difficult to verbalise what has been learned or to state what perceptual techniques they employ. The same problem occurs in radar interpretation training (Lichte et al.[56]). Some studies have marginal relevance to perceptual learning in the radar observer (e.g. Mayer[245]; Hake and Ericksen[246]) but they have even less relevance to map reading which seems to be more concerned with spatial abilities than form and pattern discrimination.

The abilities relevant to map reading are generally ill-defined, and therefore the validity of training procedures in map reading must be suspect. The criteria used to judge the progress of training and the attainment of map reading proficiency rely more on *ad hoc* empirical measures than on standardised formal testing. It becomes difficult to tell if the map reading skill of an individual could be further improved by training, or what kind of training would offer the best prospects for such an improvement.

Various studies have provided clues on how training in map reading might be improved. The relevance of map reading for the navigator led to the inclusion of a test of map reading skill in a selection battery based on a job description of the navigator (Carter[423]). Topographical orientation has been established as an independent factor, which cannot be predicted in the individual from measures of other apparently related factors such as spatial orientation (Clarke and Malone[270,301]). Geographical orientation was considered by Lichte et al.[56] as an ability which was learned, to the extent that information could be continuously incorporated by a nearly automatic process to maintain orientation; they therefore recommended that research should be conducted to find out how training improves orientation. Training, for instance, has helped map users to interpret contour lines, particularly with three dimensional rather than two dimensional material (McGuigan[631]). Map reading performance in the laboratory was positively correlated with practical map reading in the field, perhaps because of a learning effect, and general intelligence was correlated with task performance involving map reading (Tallarico et al.[266]). Accuracy of direction estimation (Gray et al.[351]) and of the estimation of angles (Waller and Wright[350]) can be improved by training, and direction estimation was an important criterion for navigation skill on the ground (Findlay et al.[249]). Training for land navigation also included instruction in dead reckoning and in relating map and terrain (Follettie[750]). Numerous postulated factors relevant to map reading skill on the ground have been evaluated by subjective questionnaire methods (Cogan et al.[250]).

Three kinds of research, in addition to studies more directly concerned with the reading of aviation maps, may suggest training guidelines for developing map reading skills. The three are studies of the development of map reading

skills in children and adolescents; studies of mental maps and cognitive aspects of map reading; and studies of search strategies in the perception and interpretation of complex information displays.

A summary of research on children's map reading skills by Rushdoony[259] indicated their progressive development and the effect of systematic instruction on the learning process. Even for young children, instructions seemed to offer the best prospects of map reading success (Plumleigh[263]), and their ability to understand map symbols suggested that the cartographic aim of making the meaning of symbols self evident had largely been achieved. Dale[497] concluded that the ability to read maps was related to spatial intelligence, and that children found it relatively simple to learn the basic language of maps. Only certain kinds of instruction and experience are effective in relation to map reading (Savage and Bacon[751]). Programmed instruction may not necessarily be better than traditional methods (Gildea[440]), but the use of stereo pairs of aerial photographs showed some promise (Riffel[752]). The above research with children has to be set in the context that little is known about the development of concepts which aid map reading (Poh[632]). Fischer[260] also noted the paucity of evidence about factors related to the ability to read and interpret maps.

Recently, man's conceptual framework of his environment and his orientation within it has received much more attention. The concept of the mental map, explored by Ryan and Ryan[83] and explained by Griffin[88], has been re-examined; quantitative methods have been applied to the study of mental maps (Gould and White[82]; Canter[294]). A series of papers (Downs and Stea[290]) represents recent thinking. Hart and Moore[298] traced the development of spatial cognition in the child and adult. Kaplan[510] extended the notion of the cognitive map beyond the confines of traditional orientation problems to broader problems of cognition. Downs and Stea[511] treated cognitive mapping as an adaptive process encompassing various perceptual frameworks. While such studies provide a broader theoretical framework for considering geographical orientation and map reading, and as such may go some way towards countering McGrath's[316] conclusion that "virtually nothing is known about the variables that influence the geographic orientation performance of man", they nevertheless do not lead directly to practical guidelines on training for map reading. Research on mental maps is discussed in more detail in Chapter 3c.

Research studies on the interpretation of complex visual displays in aviation contexts have had a variety of origins. Some have examined several dimensions of information displays comparatively, to identify factors relevant to performance (Siegel and Fischl[209]). Some have considered a single coding dimension in relation to the range of its operational utility (e.g. colour vision, AGARD[575]). Some have been concerned with developing valid measures such as eye movement recording (Kalk and Enoch[457]), with the feasibility of imposing more efficient search patterns (Enoch and Townsend[448]), or with restricting search time (Richman et al.[449]). Attempts have been made to define the conceptual problems which appear to limit the ability to interpret maps or aerial photographs, and in particular to assess the correctness of the images of relief which maps or aerial photographs engender (Gamezo and Rubakhin[628]). Image degradation has been employed, both to define the psychophysical attributes of the image which determine subjective assessments of its visual quality (Sadacca and Schwartz[215]), and to demonstrate the effects of a degraded image, as encountered in aerial haze, on search patterns, search success and search time (Townsend et al.[450]). The interpretation of complex visual displays is covered more fully in Chapter 3b.

Olson[505] concluded that even a small amount of training could aid map reading by clarifying the nature of the required tasks. For certain tasks associated with maps, training may reduce variability of responses rather than give a general improvement in performance in absolute terms (Fischer[260]; Larve et al.[451]). The aim of training aircrew to acquire a single map reading skill applicable to navigation in all weathers (Barnard[753]) may be unattainable if map reading employs a multiplicity of skills. Granting Barnard's contention that "the art of map reading consists of being able to visualise without effort the physical and cultural features represented on a map by symbols", it does not necessarily follow that this could be achieved, or that all map reading skills could be subsumed under that description.

Borden[443] tabulated map-reading training time for various US training commands, distinguishing between classroom, in flight and informal training, and between total training time, VFR navigation training and map reading training. His findings included the following points. Very little time was devoted to map reading training, and much of it was concerned with cartographic principles rather than active use of the map for visual referencing. Much map reading training, conducted before, during and after training sorties, was considered to be uneconomic. No research was being conducted to improve training in reading aviation maps. There was almost complete reliance on on-the-job training. Training had been viewed too narrowly, and the problem should be treated as one of earth referencing rather than map reading. The continued emphasis on the aircrew's ability to read the map could be misconstrued in an era of burgeoning navigation displays intended to reduce map reading, but the need to relate the map and the outside world persisted with new display technology, and selected waypoints still had to be identified in flight. Borden's[443] conference report clearly demonstrated how seriously the training of aircrew to use maps had been neglected.

Barnard et al.[129] reviewed the training of map reading in helicopter pilots in the British Army Air Corps and found that whereas basic navigation and map reading is taught during basic training (e.g. the meaning of map symbols, relief appreciation, the difference between map reading on the ground and in the air), after this period aircrew learn from "on-the-job" experience and tend to develop their own personal styles and procedures. Navigation exercises are a regular feature of continuity training on squadrons but their value might be improved if they could be more closely related to operational conditions in unfamiliar areas. Map reading training requirements for nap-of-the-Earth helicopter flight are discussed by Saathoff[754].

13d SKILLS AND ABILITIES OF USERS OF AVIATION MAPS

The design of efficient instructional programmes can only be achieved once the perceptual skills, concepts and abilities involved in efficient map use have been identified. The value of a training programme depends on whether it concerns a skill that can be modified by training or a basic perceptual attribute of spatial ability.

Although there had previously been compilations of map reading skills evaluated subjectively (Cogan et al.[250]), a specific objective of the conference on training pilots in the use of aeronautical charts (Borden[443]) was the identification of the map reading skills and knowledge required by pilots. The conference participants compiled a list of skills, and subsequently rated them according to their importance for training. Four different phases of a mission were distinguished – preparation, planning, en route navigation and target-area navigation – and the skills are given below for each phase, in their rated order, with the most important first.

(1) Preparation Phase

Knowledge of the relationships between chart scale and size, shape generalisation, and density of portrayed features.
Knowledge of the vertical and horizontal accuracy of portrayed features.
Knowledge of the limitations of the intelligence base from which the chart was compiled.
Knowledge of the criteria used by cartographers in selecting features for portrayal.
Knowledge of the criteria used by cartographers in representing features that are subject to seasonal change.
Knowledge of the range of features that are represented by a given symbol (e.g. the different kinds of mines represented by crossed picks).
Knowledge of how chart production practices affect the accuracy of portrayed features.

(2) Planning Phase

Ability to predict what a feature will look like in the real world from planned direction of approach and look-down angle.
Ability to determine terrain shape through interpretation of contour lines, shaded relief, and spot elevation.
Ability to predict the visibility of terrain features from planned position along course.
Ability to recognise barriers, funnels, general orientating features, and less-than-optimum orienting features that can aid in maintaining orientation while on-course and aid in re-orientation if off-course.
Ability to recognise patterns of features associated with a primary checkpoint that will aid in its identification.
Ability to select features that will break mask at sufficient distance from the aircraft to allow time for positive identification.
Ability to predict the detectability of terrain features.
Ability to determine the interval at which checkpoints should be selected to minimise navigation error while allowing sufficient interval to attend to other en route tasks not related to navigation.
Ability to infer unportrayed features, such as vegetation cover, presence of a bridge, railway junction, etc.
Ability to selectively attend to one class of information in a field of heterogeneous information (e.g. to consider the road network only).

(3) En route Navigation Phase

Ability to anticipate checkpoints in time.
Ability to detect checkpoints.
Ability to differentiate checkpoints from other similar features in the same geographic area that may or may not be portrayed on the chart.
Ability to recognise disorientation.
Ability to obtain information from the chart with a minimum amount of head-down time.
Ability to visualise relative movement over the chart.
Ability to evaluate unplanned features under conditions of disorientation in terms of their probability of being portrayed on the chart, probability of being located on the chart, and probability of differentiating them from other similar features on the chart.
Ability to maintain a general awareness of position by estimating distance and bearing from gross orienting features.
Ability to attend selectively to those features in the visual scene that are portrayed on the chart.
Ability to ignore information on the chart that is not relevant to the task at hand.
Ability to read alphanumerics accurately and quickly regardless of chart orientation.

(4) Target Acquisition Phase

Ability to detect and identify checkpoints with reduced forward visibility resulting from decreased altitude.
Ability to determine and report location of targets by relating their position to portrayed features.
Ability to recall the spatial relationship of terrain features studied during pre-flight planning.
Ability to make visual estimates of distance and bearing from relevant orienting features.
Ability to determine position from less significant checkpoints than used on the en route portion.
Ability to recognise the predicted point of unmask (point of target availability).
Ability to change conception of relative movement over the chart with changes in chart scale and aircraft speed.

The above list of postulated skills indicates the complexity of the map reading task, and the numerous abilities involved in successful map reading. Although it primarily concerned military aviation requirements, it should not be forgotten that aviation maps are used most by general aviation pilots (Lancaster[506]). It is possible to study some of these skills by simplified methods to define the variables affecting performance: McGrath and Borden[317] required pilots to plot on the map the ground track of a film simulating low level flight, a task which the pilots found to be extremely difficult. Varying the map scale apparently led to variations in orientation strategies (McGrath et al.[318]). An alternative method was to ask pilots to recall and record their route after the mission had been completed, and although the purpose was to measure their performance, the task also yielded evidence on the level of skill which could be achieved (Borden[323]; Borden and McGrath[324]). Once checkpoints had been identified, it proved possible both to formulate accurate verbal descriptions of their location and to plot the location on the map from the verbal description (McGrath et al.[322]), a finding confirmed by Taylor and Hopkin[157]. Pilots also possessed skills to select terrain features suitable for portrayal on the map for subsequent use as checkpoints, and to select features on the map which were likely to be visible from low altitude on the terrain (McGrath and Borden[121]; McGrath and Osterhoff[325]). These series of studies helped to reveal the potential map reading skill which may be developed.

An attempt to identify the skills involved in low altitude observation resulted in the specification of four skill areas – visual search, target recognition, geographical orientation and target location (Thomas[755]). The ability to locate target areas from low level could be improved by training in the principles of perspective geometry (Larve et al.[451]). The inherent limitations of maps as representations of the surface of the earth when seen from low altitude have been described by McGrath[339] in a document intended to instruct aircrew in the principles of map reading at low altitudes. Critical errors, which may be construed as lapses of skill, were associated with continuous low speed low level navigation (Lewis[66]; Lewis and de la Rivere[360]). As expected, error magnitude is a function of scale, but not solely a function of scale (Edmonds and Wright[308]). Since geographic orientation is a learned ability, it should be amenable to improvement by training given the correct techniques, and it can reach a level of skill where the process of orientation is scarcely conscious (Lichte et al.[56]). Orientation may well be a unique skill, independent of other factors (Clarke and Malone[301]), though linked by common learning and knowledge to various measurable attributes (Dornbach[292]). McGrath[316] remarked that there was no known method of reorienting quickly a profoundly disoriented person.

Part of the skill of an experienced pilot consists of using maps before the mission to construct a mental map of the terrain, the route, checkpoints, and other pertinent information. The user's map reading ability, and mission success, may be enhanced if the map design has sought successfully to construct a satisfactory mental map in the user (Dornbach[292]). It may also be possible to treat the map as a means of identifying errors in the mental map (Downs and Stea[511]).

Map reading undoubtedly involves a multiplicity of perceptual skills and abilities. In particular, spatial abilities must be highly relevant when the map reading task involves translating the two-dimensional map into a three-dimensional model of the real world. In a factor analysis of many perceptual tasks, Thurstone[756] identified seven primary factors including three on visual orientation in space. Subsequent work has tended to confirm that there are essentially three different perceptual attributes of spatial ability (French[757]; Smith[758]; Downs and Stea[290]). The exact nature of these spatial abilities is disputed but they seem to be distinguished as follows:

(a) Spatial Pattern. The ability to perceive spatial patterns accurately and to compare them with each other.
(b) Spatial Orientation. The ability to recognise a spatial pattern, in whatever orientation it is presented.
(c) Spatial Visualisation. The ability to comprehend and manipulate movement in imaginary three-dimensional space.

Most of the available evidence (e.g. Fleishman and Hempel[759]) seems to indicate that performance on spatial tests is not significantly affected by training, and that the concepts of spatial ability involved in map reading are reasonably well developed at an early age (Blaut and Stea[760]). Satterly[761] found that two principal concepts were being used in map reading by 14-15 year old children: a general factor of perceptual reasoning and one of spatial ability. Whereas a study of adults by High[284], reported by Lichte et al.[56], found a positive relationship between performance on a geographic orientation task and a test of spatial visualisation, Clark and Malone[301] found no relation between a similar pointing task and standard tests of spatial visualisation and spatial orientation taken from the Guildford-Zimmerman Aptitude Survey. Neither of these studies involved map reading.

Hill and Burns[762] reported part of a recent study to identify modifiable skills and more stable basic perceptual attributes in adult map reading. Training improved performance on two map reading tasks, object identification and feature symbol interpretation, but the ability to interpret the shape of the terrain (slope direction) from contour lines was unaffected by training. Factor analysis of pre-training and post-training data showed a marked change in the factor structure as a consequence of training, and it indicated that the skills developed in object interpretation were not common with perceptual attributes used in the estimation of terrain shape. The authors concluded that several skills and perceptual abilities are involved in map reading, although not all would appear to be equally amenable to improvement by training. Map reading performance was also related by factor analysis to psychological variables measured from a test battery of perceptual, personality and intelligence tests. The main finding was that the post-training map reading data were relatively independent of most of the intelligence and personality characteristics. Two definite dimensions of map reading ability, and a possible third, were identified in the post-training factor structure, namely:

(1) Feature identification and recognition.
(2) Spatial visualisation.
(3) Spatial manipulation and perceptual speed.

Training affects these different abilities in different ways and the authors concluded that a successful measure of cartographic competence must provide an indication of the individual's aptitude for the acquisition of skill in feature recognition, as well as assessing performance in the basic perceptual ability of spatial visualisation.

It is not possible to state how far the reading of aviation maps could be improved by the development of users' skills and abilities, but it seems almost certain that an application of what is known already could bring substantial benefits, and that from more research on this topic further benefits would accrue. As yet, the necessary skills and abilities have not been fully defined, and those suggested have been insufficiently validated. Once it is known what the user needs, satisfactory methods of training to ensure the acquisition of the appropriate skills and abilities will also be necessary. In relation to the known complexity of map reading skills, existing formal training seems seriously deficient, and there is excessive dependence on training by experience, and even by trial and error. However, a greater understanding of map reading skills must precede the definition of training objectives. Although certain attributes, such as the maintenance of geographical orientation, and map reading skill itself, may be relatively independent, and hence not correlated highly with other factors, nevertheless efforts should be pursued to set map reading skill in a broader context of spatial reasoning, verbal abilities, strength of imagery, general intelligence, or other measurable dimensions. A full understanding of map reading entails a knowledge of its relationships to the attributes of the individual as a whole.

CHAPTER 14

THE ASSESSMENT OF AVIATION MAPS

14a MEASURES OF TASK PERFORMANCE

In designing a map it is necessary to know how the map will be used. In assessing a map it is equally necessary to know what the map is for. It cannot be judged in isolation. An aviation map is seldom used solely for one purpose. Therefore it cannot be fully assessed by a single task or a single measure (Murrell and Hopkin[763]). Just as task descriptions can serve as a basis for deciding what information must appear on the map, so they can also be used to select a range of tasks which collectively represent the envisaged functions of the map, and may therefore provide a general assessment of it. Not all the tasks from this range may be needed for assessing the efficacy of the map for more limited or specific functions.

Whatever the methods chosen to assess the map, the problem arises of establishing the credence which should be given to the findings. Their authenticity is mainly a function of two factors, reliability and validity. Reliability is usually proved either by demonstrating that the data are internally uniform, coherent and consistent, or by repeating the assessment to show that the same findings would be obtained again. Certain simple checks can be done to gauge reliability. Unreliability in experiments on aviation maps often occurs because data have been gathered from too few subjects, reducing the confidence with which findings can be generalised. Less commonly, insufficient data have been gathered from each subject. Confounded experimental designs, which permit the data to be interpreted in more than one way, also curtail reliability.

Validity concerns the extent to which the measure is actually what it purports to be, and the extent to which it is appropriate and relevant. Normally, an assessment method must possess both true validity and face validity. True validity occurs when a measure really is what it is claimed to be, and possesses the degree of relevance which it is claimed to have. Face validity refers to plausibility, that is the extent to which the measure seems sensible and suitable for its intended purpose, from the point of view of those performing the tasks. Validity is reduced, often to an unknown extent, if the conditions under which performance is measured differ from the envisaged operational conditions; for instance: a flight simulator rather than an aircraft; a quiet environment rather than a noisy one; a stable environment rather than a vibrating one; an optimised display rather than a degraded one; fixed rather than variable ambient lighting. Validity is reduced when the effects of different conditions on performance are a matter of speculation rather than fact. Much effort is often expended on proving that experimental conditions are a close enough approximation to operational ones so as not to impair validity significantly.

There is no standard method for assessing a map nor is there likely to be in the future. Numerous performance measures can be employed, as many and as varied as are the tasks that are carried out on maps, but the findings may be an artefact of the measures chosen. Performance measures, even when reliable and valid, may yield disappointing results: comparisons between maps may fail to reveal significant differences; expected improvements associated with changes in map content and design may not appear; the map user may be unable to understand all the information which the map contains; some human factors problems associated with maps may have no satisfactory solutions, such as finding an adequate replacement for colour coding under monochromatic lighting conditions. Such findings must not be dismissed just because they are inconvenient or annoying, for they may be of great practical value. It can be disconcerting to the cartographer to discover that a change is very important to him seems unimportant to the user, but it may nevertheless be a correct and significant finding, if the performance measures are both reliable and valid. On the other hand, non-significant results based on measures that have low validity and reliability can be seriously misleading such as when they fail to demonstrate the adverse consequences of a retrograde design change.

Performance measures generally refer to tasks which can be done using a map. Performance can be expressed most simply as success or failure. Common measurable indices of performance, termed dependent variables in a controlled experimental design, are speed, accuracy and consistency. Scores on these dimensions are aften evaluated by relating them to a criterion representing perfect, optimum, or desirable performance. Individual differences are normally assessed [illegible] dependent on the nature of the task and the skills and abilities of the subjects. Sampling errors and the effects of learning during the course of an experiment may seriously reduce the reliability and validity of the results [illegible]. Certain measures of performance, such as eye movement recording, may be descriptive rather than [illegible]. Some [illegible] subjective assessments are best treated as performance measures: a man may say 'yes' or [illegible] labelled keys can be an experimental artefact (Shaw and [illegible]

Performance measures have to be suitable for the task, both in their relevance and in their level of complexity. Some of the simplest measures establish limits of human capabilities relevant to maps. Evidence on differences which can be successfully discriminated depends to some extent on the measures selected and on the experimental material chosen. When several performance measures are used, it is important to show whether they are independent or related.

One common measure of performance is accuracy, where a given response is compared with the correct one on a quantifiable dimension providing data on an equal interval or ratio scale suitable for parametric statistical analysis, if the distribution is normal and has homogeneity of variance. Cartography has been concerned with accuracy more in map production than in map use (Rhind et al.[519]). Accuracy is used in visual tasks of location, of identification, of discrimination, and of interpolation. It can apply to a variety of psychomotor tasks, such as plotting routes or checkpoints, positioning cursors, annotating the map, aligning or superimposing collateral material, correcting errors, and measuring distances and angles. It can also apply to decision making and information processing tasks involving higher mental functioning, such as counting, classifying information into categories and subcategories, interpreting the nature of portrayed relief, route selection and planning, tactical interpretation, reading grid references, and converting map information from one form to another, as in giving a verbal description of map features. It can apply to tasks involving memory, such as for the meaning of cartographic symbols, the degree to which briefing instructions can be recalled, and the correspondence between an actual mission and recollection of it afterwards (Borden and McGrath[324]). It can apply to continuous tasks, such as navigation during a mission, the closeness with which the actual mission followed its planned route, and the monitoring and updating of navigational information. In the performance of many aviation tasks with maps, accuracy is the most obvious and widely used measure. However, two conditions should be fulfilled to ensure its effectiveness: firstly, it is essential to know what level of accuracy is required to meet operational requirements, and secondly, there must be independent objective quantitative criteria with which the obtained performance can validly be compared, and which serve as indices of accuracy. The value of accuracy as a measure is critically dependent on the nature of these criteria. Adequate criteria may not always exist (Goff et al.[765]).

Accuracy is not the same as precision, which is much less useful as a performance measure, and can often present practical scoring difficulties. Precision is a property of the obtained response and needs no independent criterion. The difference between the concepts can be clarified by an example. Suppose two checkpoints are described as 10 km. apart. This is not precise, and it may or may not be accurate. If they happen to be exactly 10 km. apart, the original description is accurate, and to describe them as 10.00 km. apart is being precise as well. Measuring them as 9.67 km. apart is still being precise, but no longer accurate if the distance between them is actually exactly 10 km. Knowledge of operational requirements will suggest the appropriate degree of precision, for instance in grid referencing (Taylor and Hopkin[151]) but this must be a function of map scale (Edmonds and Wright[308]), taking into account the known sources of error in map production (Gammon[113]). Map symbols, particularly on large scale maps, may be located with a spurious precision if measured with an exactness which grossly exceeds that achieved during map production.

Errors are a performance measure in common use for map assessment. Errors may be made on almost any task. Failure to detect a given symbol on a map following visual search may be treated as a detection error. This, and other performance data, may be suitable for analysis by Signal Detection Theory procedure (Swets[618]) when the display is presented under degraded viewing conditions which may induce high false positive and false negative detection rates. Failure to identify a given symbol correctly may be treated as an identification error. This occurs most frequently with degraded displays and during training with inexperienced subjects. Identification error rates do not take into account the kinds of errors or confusions that have been made. For operational reasons, certain confusions may be more critical than others. Consistently confused symbols are a more serious problem than random confusion. Taylor[111, 100] has demonstrated how Information Theory can be applied to map evaluation to provide an index of the confusability of map symbol sets which would not be taken into account by simply counting error frequencies.

Sometimes inaccuracy is treated as an error, and the difference between the two becomes arbitrary. Again, an example may clarify the distinction. Suppose the task is to mark a position on a map, given by its grid reference. If the marking is near but not exactly corresponding to the true position, then this may be scored as correct, within acceptable tolerances, but nevertheless inaccurate. As the gap between the true and marked position widens, at some point the discrepancy becomes unacceptable and the marking no longer is scored as correct but as an error. The size of the acceptable discrepancy is not absolute. Giving a six figure grid reference calls for greater precision and implies a lower tolerance of error than a four figure grid reference would. Measures of error share with measures of accuracy the requirement for independent criteria. Errors may be of omission or commission, both of which can have great operational significance. In general, measures of error are applicable to the same tasks as measures of accuracy, and to further tasks also where the man has failed to perform a required function.

For statistical reasons errors may need to be treated as nominal or ordinal data, suitable only for non-parametric analysis (Siegel[766]). The frequency of error trials, expressed as a percentage of the total, is a commonly used index of performance. CEP, that is Circular Error Probable, is a summary index of radial error commonly used in the assessment of navigation and weapon aiming system performance. The 50% CEP is that radius from the target, aiming point, or checkpoint that encompasses 50% of the positions actually obtained in attempting to hit the target. A 50% CEP of 200 metres indicates greater accuracy than say a 50% CEP of 300 metres. For a given data set, the 85% CEP will be greater than the 50% CEP, but takes into account gross errors. Unlike the distributions of individual radial errors, which tend to be highly skewed and clustered about zero, CEPs are more likely to be normally distributed and hence subject to parametric analysis. Radial error does not measure angular displacement or veering tendencies.

Speed (time for task completion) is a further common parametric measure of performance, of vital operational significance in the many aviation contexts where map viewing time is limited. Search time is a common measure of map legibility (Bartz[194]) but with complex tasks the relationship between speed and other measures of performance, such as accuracy and the information assimilated, understood, or remembered, may not be straightforward. If task performance is faster, with no measurable decrements on other performance measures, this may indicate learning and the acquisition of map reading skills. On the other hand, speed and accuracy may not be correlated or an increase in speed may be achieved only by a reduction in accuracy. Generally, it is advisable to measure both variables to check their relationship.

Measures of speed of performance can be applied only where the task as a whole, or identifiable parts of it, can be defined by specific actions, instructions or events, since the onset and completion of each task or part must be discriminable enough for the times of their occurrence to be clear and unambiguous. The distribution of times is aften skewed when the experimental task requires "instantaneous" responses, such as pressing a button as fast as possible after the onset of a stimulus, known as reaction time tasks. The distribution of reaction times should be altered to correspond to a normal distribution by a suitable arithmetic transformation, such as a logarithmic transformation, in order to comply with the assumptions necessary for parametric statistical analysis (Winer[767]).

For operational purposes, measures of consistency of performance may be vital. Consistency is not a factor measurable on its own, but it concerns the distribution of data (e.g. standard deviation, variance, range) from other measures such as speed, errors or accuracy. Parametric statistical analyses compare both the means and standard deviations of data samples in deciding the probability that they come from the same or different populations.

The above measures of performance imply the study of activity in performing the task, and objective data are normally gathered by recording actions during task performance. Certain other measures are directly concerned with the activity associated with performance rather than with the performance achieved. Traditional time and motion study emphasised this aspect, as do analyses of the nature of skill. However, the clearest example of activity *per se* as a performance measure is probably eye movement recording. This technique, properly employed, can show which sources of information are used in performing a task, and how time is allocated among them. The effects of changes in the tasks, in the information sources, or in user's skill, can be related to changes in fixation dwell times, sequences, patterns and inter-fixation intervals, and distances between successive fixations (Richmon et al.[449]). Interpretation of scan patterns is complicated by the fact that information may be obtained from the peripheral visual field as well as the point of fixation. Defining the information being used can give insight into processes of problem solving and decision making, which otherwise are difficult to study by performance measures. Whereas solutions to problems or decisions reached can often be inferred from measures of performance, the preceding stages of selecting, processing and interpreting information can be difficult to examine empirically. Although performance measures can be used to test whether map symbols can be discriminated, there are difficulties in discovering how well the user understands them, since the visual symbol may have to be expressed verbally to obtain responses, and the process of investigation may itself modify the user's understanding.

The measurement of performance is itself subject to error and inaccuracy, and findings have to be interpreted accordingly. Errors may be caused by well-known inadequacies and biases in interpreting data, for instance, convergence towards a standard measure; rounding-off of numerical estimates; undue influence of recency on decision making; conservatism in estimating trends and proportions from data. Alternatively, errors may be attributable to inadvertent omissions and carelessness. The magnitude of errors within the data, and of their consequent effects, can normally be assessed. Experimentally induced errors can often be eliminated or balanced out by using the appropriate experimental design. In practice, it is futile to attempt to measure sources of error and inaccuracy in the map, if they are of the same order of magnitude as the known sources of error within the method of measurement.

Data from performance measures are normally intended to be analysed statistically. It is necessary to verify that the quantity and distribution of data, and the experimental design, allow the legitimate use of the proposed statistical methods. The statistical significance of differences must be interpreted with caution and in a broader context. A difference in performance which has an extremely low probability of being obtained by chance may be small in absolute terms and operationally trivial. One alternative map design, for instance, may be significantly better than others statistically, but it may still be operationally unacceptable for other reasons. A single operationally dangerous error or omission may be sufficiently serious to rule out an otherwise satisfactory option.

14b SUBJECTIVE ASSESSMENTS

Map interpretation is a highly subjective process. Many objective measures of task performance record subjective events indirectly. Sometimes there is a close correspondence between objective performance and subjective events, as in tasks where the map reader must mark all examples of a designated cartographic feature. The efficiency of eye scan patterns, in theory, should be a good guide to the effective arrangement and perceptual organisation of the display. Most of the time, the performance measure is a highly simplified record of the outcome of the corresponding subjective decision making processes, as when the map reader is required to mark on the map the route he selects for a particular mission. Sometimes the nature of the task is so subjective that performance measures cannot adequately express it, as in the formation of attitudes about the efficiency of the map for its intended purposes. The tactical interpretability of maps could be assessed by series of well designed tasks, but it is often far simpler and not necessarily less reliable or valid to ask subjects to rate the displays in terms of their efficacy (e.g. Siegal and Fischl[208]; Taylor[222]). Subjective

assessments may therefore range from those which duplicate performance measures, through those which explain, amplify, clarify or complement performance measures, to those which provide relevant information about the map which could not be obtained by performance measures, or in any other way. The role of subjective assessments in relation to other kinds of measurement therefore varies.

The problems of reliability and validity, noted with performance measures, apply with equal force to subjective assessments. It may be difficult to establish what credence should be given to subjective data, but it is important to attempt to do so. Respondents normally report their subjective impressions honestly, and wilful attempts to mislead are rare; but subjective assessments can be influenced by numerous factors of which respondents remain unaware. Some of the main sources of influence are the following: –

(1) Subjective assessments may conflict with objective evidence: a map which is familiar or looks attractive (e.g. colour coded) may be viewed as more efficient than it really is. Subjective assessments of confidence in task performance often differ from the objective evidence when the task is carried out under stress. Deterioration in performance can fail to be detected by the subject.

(2) Subjective assessments are influenced by expectancies: a map user may interpret what he sees on the map as what he expects to see rather than what is really there. Maps of desert regions may show features which are almost invisible, because the cartographer abhors blank spaces, but a route may then be planned to follow expected visible checkpoints which are in fact not visible. A map may be subjectively assessed as good for a given operational requirement when new codings are radically, but unknowingly, misinterpreted in accordance with old meanings.

(3) Subjective assessments are influenced by attitudes: early impressions of the usefulness of a map, whether favourable or not, tend to become entrenched, to be resistant to contrary subsequent evidence, and to introduce bias in further judgements of the map.

(4) Subjective assessments of a map, and of the tasks it can be used for, are influenced by experience with other maps; if one map has been of no help in a particular task, it may be assumed that no other map could be useful.

(5) Subjective assessments imply that the questioner or the respondent selects themes and controls the topics and their emphasis: there may therefore be bias both in the topics on which data are gathered, and in the weighting and interpretation of the information obtained.

(6) Subjective assessments often require the man to act in some ways as a monitor of his own performance, without adducing evidence of how well he can fulfil this role.

(7) Subjective assessments may be based on evidence which is incomplete, irrelevant or misunderstood, but it may not be possible to establish the quantity and quality of the data on which the assessment has been made, or to discover what relevant evidence has been ignored.

(8) Subjective assessments may represent the views of one person, a group consensus, or a partial convergence towards a norm: it may be difficult to ascertain how far the subjective data have been influenced by others, by the questioner or by the stated purpose of the assessments.

(9) Subjective assessments may vascillate over a short period, and be greatly changed by minor factors, particularly during a brief assessment of something new, whether a map or a display: the assessment made may therefore depend unduly on the timing and the particular circumstances prevailing.

(10) Subjective assessments may generate spurious findings; in particular, opinions, if solicited, may be elicited, even when none are held.

Despite these caveats, subjective assessments can be most useful and should normally be obtained. They should preferably be related to performance measures, for each can be used to assist the interpretation of the other. If according to performance measures one map is better than another, it is important to know whether the map users realise this. Users act not on objective evidence, which they may not know, but on their subjective assessments, which represent what they believe. If subjective and performance measures yield contradictory findings, such as in McGrath and Borden's[121] study of the efficacy of an experimental map for low altitude, high speed flight, the operational consequences must be established and the reasons for the contradiction explained. Some users may be reluctant to accept that a new map could be more efficient than the one with which they have long been familiar, and equally reluctant to concede that a visual coding which they like could be inefficient or misleading. This problem could be avoided, if it is anticipated and if aircrew are instructed about the reasons for the change.

If a map is judged solely by the results obtained with it, and no insight into the reasons for the results is sought, subjective assessments may be deemed to be irrelevant. This point of view, more common in the past than now, can be held about the operational use of maps, and about methods for their evaluation. Subjective assessments, as well

as providing valuable data, carry the bonus of demonstrating to the user that his views are welcomed. The user can contribute, from his experience, evidence of a kind which no-one else possesses, and it should be gathered and applied. Claims that there are as many different answers to a question as there are people questioned should raise queries on the professional competence of the questioner, since correctly structured and phrased questions should not lend themselves to a multitude of answers.

Many kinds of subjective assessment of aviation maps can be made:–

(1) The assessment may be of the map as a whole, or of any functions or features of it. Methods include questionnaire surveys, interviews and briefings, at various levels of structuring and formality. They may refer to the whole map as an information display, especially if its aesthetic attributes or atttitudes towards it are being explored, but more commonly they postulate a particular operational role and obtain opinions in relation to it, from those with relevant experience who can give authoritative replies. The results can be reported in the form of either requirements or preferences.

(2) Subjective assessments may describe how the map is used, and the process of map reading. Reports can be obtained on the procedures adopted, the sequencing and duration of actions, the equipment utilised and its method of use, on the route flown, on the cartographic information needed for a particular task, and on the interpretation placed upon information actually used. What is not used or not understood may be of greatest significance. What is gleaned and remembered after undirected study of the map may reflect the map reader's interests or the visual balance of the map contents. Reports of personal experiences, problems and difficulties, speculative explanations and hypothesising can give substance and meaning to bald objective descriptions of task performance.

(3) Subjective assessments may be concerned with perceptual aspects of map reading which have no objective equivalent or counterpart. Subjective assessments have to be used to study the psychophysical scaling of symbols in equal appearing intervals, induced colour contrasts, apparent density of map information, and inferred relationships among portrayed features. They are essential in describing mental maps and the processes of disorientation and reorientation. Objective and subjective meanings of what constitutes new data may also differ; information which has always been present is new when the map reader first notices it or understands it.

Subjective opinions and objective measures of task performance have been viewed as complementary processes in the evaluation of aviation maps for high and low level flight (Murray et al.[128]; Schreiber[25]; Howey[336]). Whether maps meet users' stated needs has become a matter of general concern to cartographers (McGrath and Kirby[768]; Kirby[769]), not only in aviation. Drivers' views on road maps have been obtained (Sheppard and Adams[770]): Astley's[651] conclusion, that 'many current road maps show more of the things road users say they do not want than those they do', has a familiar ring. In U.S. Army mapping, direct contact between map producers and users was fostered, with the former observing manoeuvres using maps, and surveys were also conducted (Sorrentino[744]). Survey methods identified the widespread practice of using hand-held white-light torches to read maps in the cockpit because the cockpit lighting was inadequate (Milligan[411]; Taylor[348]), a practice which largely negated cartographic efforts to conform to red light legibility requirements in map design. Opinion surveys by questionnaire have collated user criticisms of specific aviation map series, and enabled improvements to be formulated (Lakin[633]; Anon.[507]; Lakin[340]).

Murrell[131] demonstrated that experienced aircrew were able to select items for inclusion on a map for a given operational role which closely corresponded with those visible from the air at the appropriate altitude. Instead of asking users to select cartographic categories for inclusion on the map, he presented them with a large number of map segments, on which every feature had to be assessed in terms of its operational importance. General categories were derived from the large number of specific responses, an experimental method which he claimed (probably correctly) was both more orthodox and more valid than asking general questions. The two methods did not give the same answers. Unfortunately, most reported findings concern general questions about legend categories (Hopkin[771]). A further change of emphasis has been to invite user opinion on aviation maps (Wright[347]). Subjective scaling assessments of the utility for navigation in LAHS flight of eighteen 1:250,000 scale maps were reported by Taylor[222]. Subjects rated each map on a numerical scale of 0 (useless) to 100 (extremely useful). The results were analysed by principal co-ordinates analysis. Two axes accounted for a large proportion of the variance. These were identified as corresponding broadly to an information density/clutter dimension and to the adequacy of relief representation. User preferences favoured maps with low information density and relief representation by layer tinting. Subjective scaling techniques can be used to identify the main psychological dimensions of maps and to quantify subjects' preferences for different products but it does not necessarily follow that maps which load highly on preferred dimensions are necessarily best in terms of performance criteria.

From detailed subjective reports of what topographical information is useful, criteria may be derived for selecting features for portrayal (McGrath and Borden[121]). Subjective evidence can also be obtained after a mission on how the map had been used during the course of it (Borden[323]; Borden and McGrath[324]). The choice of words to describe map contents is largely a subjective process which needs subjective evidence for full elucidation (Murrell and Hopkin[763]). Performance measures may be less sensitive than subjective ones in establishing whether the user had enough time to

perform his tasks. Similarly, in comparing maps with collateral material, performance measures can indicate success or failure, but subjective evidence of the processes involved may be more helpful in suggesting how success could be enhanced.

In choosing map symbology for scaling quantitative data, it is necessary to understand the psychophysical relationship between the physical dimensions of the symbols and their perceived scaling (Stevens[176]). This understanding can be applied when choosing sets of patterns, shadings or symbols within any dimension (Jenks[746]; Jenks and Knos[94]). The principle can be extended to judgements of more abstract concepts such as information utility (McKendry et al.[772, 773]). It has also been applied to test whether a series of psychophysical changes which ostensibly portray a single dimension sequentially appear to the user to do so logically (Hopkin[640]). A psychophysical dimension may be assessed according to further subjective criteria. For example, colour on maps may be examined for induced colour contrasts (Audley et al.[189]), or for its associative properties (Van der Weiden and Ormeling[501]).

In experiments on the design of scales of layer tints for aviation maps, psychophysical judgements of apparent progression and perceived contrast may indicate differences that are too small to be detected by performance measurement but that affect subjective preferences (Taylor[641]). Small differences in the progressiveness may have no measurable effect on map reading performance but they may be a major determinant of the face validity of a layer tint scale, which is an important influence on the initial acceptability of a new product.

The recent interest in mental imagery in general (Sheehan[252]), and mental maps in particular (Gould[295]), relies on subjective assessment, to the extent that advances in knowledge depend greatly on the evolution of acceptable subjective assessment methods. A mental map, being a subjective frame of reference, can be studied only in subjective terms. Data obtained in verbal form or in graphic form depend on the facility to verbalise or to draw, as well as on the mental map itself. It can be reasoned that the better the mental map, the better should be the subsequent navigation. Navigation is easier in familiar terrain, presumably because the aviator uses topographical information stored in memory and is not entirely dependent on cartographic information. Over-dependence on mental maps as a conceptual reference system for navigation may lead to a greater probability of geographical disorientation (Taylor[774]). The problem with studies of 'externalised' mental maps, is that the act of drawing the map involves skills and abilities that may be different to those of utilising the mental map during navigation. A poorly drawn mental map may not necessarily be associated with poor navigation performance. This relationship needs to be tested. Without agreement on methods for the subjective assessment of mental map imagery, it is impractical to consider how maps could become more compatible with that imagery or whether making them so is a sensible objective. Although performance measures can be employed, they are comparatively crude, and fail to reveal the complexity, variety and richness of the subjective phenomena.

14c CHOICE OF TASKS AND EXPERIMENTAL MATERIAL

The reliability and validity of empirical assessments of aviation maps are affected by the choice of tasks and experimental material. Ideally, the entire range of tasks that are likely to be performed with the map should be included in the evaluation, as determined from task description (cf. Chapter 6) and from a knowledge of operational requirements. Also, the entire range of products should be tested, if possible. In practice, the variety of possible tasks, and the number of sheets in a major series, are usually too great to allow a comprehensive evaluation to be undertaken, and the researcher has to select a representative sample or "battery" of tasks and experimental material. Alternatively, the researcher may choose to evaluate a map using the most important task or tasks, examining only critical functions, as defined by operational requirements. The feasibility of field and laboratory studies is a further factor that determines the form of assessments. The experimental material may be limited to a prototype sheet of one area, chosen because it is exacting to portray cartographically, because it contains most topographical features, because it is representative of the series as a whole, or because the trial is restricted to areas where field studies can be carried out, such as training areas and low flying areas.

Choice of Tasks

Questionnaire surveys tend to elicit information on a wider and more comprehensive range of tasks than do laboratory or field studies. Even when respondents are implored to obtain practical flying experience with a prototype sheet (Lakin[633]), there are usually doubts about the reliability of the findings, particularly when they are controversial. Surveys after a series has gone into service, when it is more likely to have been tested by users under operational conditions, probably have a higher degree of reliability (Lakin[340]) but they are often too late to lead to radical changes in the production specification. Despite these problems, map production agencies usually choose to gather "informal" opinions from operators rather than initiate objective, controlled evaluations. Typically, a wide spectrum of opinions is obtained and judgements have to be made on which are likely to be reliable, and which must be treated with caution. This may be the quickest, most cost effective method for the test and evaluation of cartographic products but it is unlikely to elicit optimised designs. Furthermore, conservatism in subjective assessments means that radically new proposals are seldom deemed acceptable.

Most map reading tasks can be subdivided according to the fundamental perceptual and cognitive processes of search, detection, discrimination, recognition, identification and memory; performance on these aspects of the tasks can be studied separately. Generally, these processes are concerned with the decoding and assimilation of information

from the map and relate especially to psychophysical aspects of map communication, i.e. effects of fonts, sizes, line widths, contrasts, etc. In practice, map reading involves complex decision-making and judgement based on the map reader's interpretation of information on the map, as in selecting a route, visualising a group of features, correlating patterns, and maintaining geographical orientation (Board and Taylor[458]). To assess the effectiveness of the map for more complex tasks such as these, the researcher must simulate them as realistically as possible and measure performance on operationally acceptable criteria.

Unfortunately, experiments on maps, as on most topics, have concentrated on themes which lend themselves readily to experimental methods, but which do not necessarily pose the most important problems. Search and identification have been by far the most common tasks used in map evaluation partly because of their universal relevance, and partly because of the simplicity of performance measurements – search time and identification errors.

Landis et al.[193], Bartz[194, 504], Beller[195], and others have correctly emphasised the importance of search time as a dependent variable in map research. Undoubtedly, the ability to locate cartographic information speedily is a vital quality of efficient map reading, during briefing, pre-flight planning and flight, and evaluations should be designed to include search performance, particularly in studies of colour coding (e.g. Shontz et al.[588]). However, as Stringer[595] observed, although maps have a wide variety of functions, their behavioural evaluation has generally been limited to search tasks. Search tasks present serious difficulties in experimental design. Search strategies adopted by individual observers are major determinants of performance. Unless the search pattern is directed by instructions or by artificial constraints such as controlled exposure of the map (Richman et al.[449]; Enoch and Townsend[448]), large individual differences occur which tend to obscure the smaller effects attributable to cartographic variables. Random search has greater face validity than a constrained scan, but even if eye movement recordings are obtained to check on random search strategies (Shaw[198]), little control can be exercised over the information attended to during non-target fixations and in peripheral vision (Hill[434]). Trials on which the target is not acquired, or is fixated but not recognised, present further problems for data analysis. Search performance is affected by the observer's knowledge of the target being sought. Again, this is extremely difficult to control except for very simple targets. Even presenting the observer with a single description or presentation of the target symbol or pattern does not ensure that all its features, or even the most salient, have been memorised nor that they will be recalled during subsequent search. A decision must also be made on whether information about the target should be presented only briefly at the onset of the trial or should be continuously available during the search period. Individual differences in the use of continuously available target information may affect search performance.

Identification of the meaning of map symbols is a fundamental aspect of all map reading. Identification tasks in map evaluations usually require the observer to name specific map symbols, often using their designation in the map legend. Type-legibility studies normally gather identification responses to place names or letters. In principal, any task which elicits symbol-specific responses could be classified as an identification task. The response need not necessarily be verbal but may involve pressing a button on a keyboard. Examples of studies which have used identification tasks in map evaluations include Koponen et al.[29, 33], McGrath[650], Marsetta and Shurtleff[560], Hitchcock[527] and Wong and Yacoumelos[528]. Taylor[111] demonstrated how the analytical procedures of Information Theory could be used to measure the kinds of errors made during identification tasks with specific symbol sets. Valuable information for the map designer is combined in the kinds of confusions made by observers during map reading. On aviation maps, ambiguity in the meaning of symbols (e.g. power transmission lines and canals) may have catastrophic consequences and must be avoided at all costs. Discriminating characteristics that seem clear to the cartographer, may not be so readily discerned by the user under degraded operational viewing conditions.

The major methodological problems with identification tasks are in the mechanics of presentation of the stimulus material and in scoring responses. Individual presentations of map symbols, as on cards viewed in the tachistoscope, change the influence of the cartographic context on identification performance. On the other hand, large map sheets pose the problem of indicating the specific feature to be identified in a given trial. Pointers, circles or grid references have to be used to specify the location of the feature without interfering with the primary task. Responses are usually restricted to a specified set of symbol names, such as the legend categories, for otherwise scoring criteria can be difficult to determine. Subtle distinctions in meaning, indicated by related features and contextual cues, or local knowledge, are more difficult to test by such simple procedures and are rarely included in map evaluations. The size of the set of alternative responses affects performance. This makes comparisons difficult between sets of different sizes, e.g. between alphanumeric and numerical fonts.

A further kind of map reading task, recognition and matching, requires the observer to assess the visual similarity or dissimilarity of symbols or patterns of features, without necessarily producing specific naming responses. These tasks rarely feature in assessments of maps *per se*, but they are common in studies of the use of maps for geographical orientation and the interpretation of collateral displays, such as reconnaissance images, radar and photographs (Daniel et al.[54, 55]; Welch and McKechnie[436]; McKechnie[218]; McKechnie and Griffin[678]; Emery[315]).

Navigation by visual referencing procedures involves making comparisons between patterns of features on the map and on the ground; maps can be compared in terms of their effectiveness in facilitating this task (McGrath and Osterhoff[325]; McKechnie[306]). A shape recognition task was used by Taylor[159] to evaluate alternative woodland symbology for the 1:500,000 Tactical Pilotage Chart. Three-dimensional relief models and profile drawings have been matched to topographical maps to evaluate alternative relief codings (Phillips et al.[267]; Taylor[774]). Visual matching is an

important task in the analysis of data on maps by geographers (Board and Taylor[458]). Experiments have been conducted with thematic maps to assess the ability of observers to recognise relationships between different distributions of geographical phenomena (McCarty and Salisbury[517]). Bush et al.[217] reported a method for studying the visual matching of patterns that is highly relevant to experiments on cartographic generalisation.

Most map reading tasks have components that fall into the categories discussed above – search identification, and recognition or matching. Christner and Ray[103] analysed the performance on five sub-tasks deemed basic to map reading:

Locating (e.g. which area contains only one HQ?)
Identifying (e.g. what type(s) of radar sites are in area C?)
Counting targets (e.g. How many barracks are on the entire map?)
Comparing (e.g. Are there more barracks in area Q than in Y?)
Verifying target data in different areas (e.g. There are two prisons in area V. True or False?)

Factor analysis of performance data obtained from an evaluation of map display characteristics (coding combinations, number of levels of coding, clustering, and number of targets) was used to extract three general task factors. Factor I, called Recognition, loaded highest on the Identifying and Verifying tasks. Factor II, called Search, loaded highest on the Locating and Counting tasks. Factor III, called Remembering, loaded highest on the Locating task and moderately highly on the Comparing task. This third factor was related primarily to the structure of the operator's task and the amount of data to be dealt with at one time. The authors did not include matching tasks in their study, but it is quite possible that matching would have correlated with all three general task factors.

Relief interpretation tasks were not studied by Christner and Ray[103]. Examples of the kinds of tasks involved in relief interpretation are given by Phillips et al.[267] and Potash et al.[775]. These include identification tasks – identifying types of landforms (hills, valleys, spur, depression, saddle), identifying whether lines run along valleys or ridges, identifying the direction of slope of lines (up, down, convex, concave), estimating the absolute elevation of points; search tasks, locating the highest elevation, the steepest slope, all areas above a specified elevation; and visualisation/ matching tasks – estimating intervisibility between points, matching profile drawings to lines on the map, matching three-dimensional models to map segments. A cluster analysis of relief interpretation tasks produced three groupings, corresponding to tests of absolute height, relative height and visualisation (Audley et al.[189]). In choosing tests of relief legibility, at least one test should be included from each of these clusters to make the assessment representative.

Laboratory evaluations of aviation maps reported in the literature have usually been concerned with legibility or ease of reading maps, measuring the speed and accuracy with which observers can find and use information on them. Whiteside[30], Crook et al.[35] and Crook et al.[36,40] measured the speed and accuracy of reading map type under red cockpit illuminations. Carel et al.[196] studied the legibility of map type in PMDs. Welsh et al.[656] and Rasmussen et al.[658] measured alphanumeric readability on approach charts and en route low altitude charts respectively. Obtaining discrete responses for topographic symbols is a more difficult problem, and researchers have used a variety of different techniques. Whiteside and Roden[31] asked their subjects to locate and mark off in 15 seconds as many aerodrome symbols as possible. Koponen et al.[331], in a study of the relative legibility of two charts under red light, measured the speed and accuracy with which subjects could identify airports or radio aids information appearing along flight lines by reading off characteristics of the features. In a separate search task, subjects were required to locate radio broadcasting stations located within the specified area. Murray[28] used similar tasks for identifying airport and radio information along flight lines. A test of the ability to identify specific natural and cultural features which could serve as checkpoints was included: this produced the largest differences between the three aeronautical charts tested. A fourth test required subjects to search for the geographic locations of seven aerial photographs taken from 40,000 feet. Only small differences were found in the numbers of correctly located positions on each chart. This was interpreted as meaning that differences in map scale (1:1,000,000 and 1:4,377,740), and concomitant differences in map content, did not affect the pilots' identification of reference points. Chisum[408] asked her subjects to search for and mark a specific named feature on the chart under either red or white light. The duration of each trial was timed by the opening and shutting of a mechanical shutter, which exposed map segments to the subjects. A statistically significant difference in errors of marking was obtained, but no effect was observed on times between the two lighting conditions.

Identification responses for topographical (point, linear, and area) and alphanumeric symbols were obtained by Taylor[100] in assessing the comparative legibility of two 1:250,000 scale aviation maps of the same area under direct and projected map display (PMD) viewing conditions. The symbol to be identified on each trial was indicated by a mask covering the symbol or a separate, identical "key map". Significant effects on times and errors were observed. In a further study, Taylor[657] used a partially restricted search task to assess the effects of red and white cockpit lighting on the legibility of the colour specifications for the Joint Operations Graphic, the Tactical Pilotage Chart and a full-coloured experimental specification, all printed using the same repromat of a sheet in the TPC series. Subjects were presented with Monochrome facsimilies of the target symbols mounted on a sheet of paper, cleared of other detail, the same size as the test sheet, in a position corresponding to the location of the target. Subjects indicated whether or not the target symbol was present or absent at the indicated location on the test sheet by pressing one of two buttons on a keyboard. On 50% of the trials the target was not present. Differences in errors and times were found for the same symbols printed in different colours and large increases in times occurred under red lighting conditions. Barnard[406] used both search and identification tasks to assess the legibility of a variety of experimental 1:50,000 scale maps for helicopter operations.

Subjects viewed the maps directly under white tungsten illumination and through image intensification goggles. In the identification task, examples of symbols cut from the maps were presented singly for identification, by verbal responses. In the search task, the target symbol was presented on a cue card. The subject then searched for the symbol on the test map and indicated its location by pressing one of four keys, corresponding to four sectors of the map. Statistically significant effects were observed on identification errors and on search times.

Field tasks and realistic laboratory tasks, in the sense that they simulate tasks carried out under operational conditions, are less common in evaluations of aviation maps than of other maps, because of practical difficulties in setting up the tasks. Tasks that involve discrete responses such as marking grid co-ordinates can be set up with comparative ease (Edmonds and Wright[308]; Taylor and Hopkin[151]). Continuous navigation tasks present numerous methodological problems (Farrell[358]), but McGrath[432] reviewed the problem and proposed several solutions based on flight simulation. A method of flight simulation, using film of actual low altitude missions, was developed and used in subsequent studies (McGrath and Borden[317]; McGrath et al.[318]). Subjects were asked to mark on a map the route that they thought the aircraft had flown given continuous time, speed and heading information, a task similar to that of a pilot or navigator monitoring the aircraft's position against a planned route. Deviations from the actual route were taken as an index of map efficacy.

Navigation systems including map displays have been evaluated by recording navigation performance of actual missions (McKechnie[306]; Lewis and Anderson[355]; Jenson et al.[776]) and simulated operations (Payne[387, 427]). Whereas navigation performance must be the ultimate tests of an aviation map, the problem with navigation tasks is that they produce data on the relative efficacy of the map product as a whole and not on the optimisation of cartographic variables. Navigation tasks may be used to demonstrate that navigation can be more accurate with a large scale chart (McGrath et al.[319]) and with a coloured chart compared with a black-and-white photographic copy of that chart (Osterhoff et al.[320]) but they do not readily yield data on methods for improving map generalisation or colour coding, unless numerous maps are tested varying a single cartographic dimension.

Tests of tactical interpretation and decision making have been used in the evaluation of maps for land navigation. A series of studies of the comparative legibility of conventional line maps and photo-based products (Berry[777]; Berry and Horowitz[515]; Wheaton et al.[504]; Hill[434]) have used a wide range of tasks, including laboratory tasks of object location, object identification, terrain visualisation, height estimation and intervisibility estimation, and field tasks of direction orientation, self location, field-to-map object location, map-to-field object identification, route planning and route following, and terrain elevation interpreation. The need to use a battery of tasks seems to be well established in this area of map assessment. Many of these tasks are relevant to map reading in aircraft at low altitudes and could be particularly useful in assessments of helicopter tactical maps (Anon.[665]; Johnson[404]). Intervisibility estimation and relief interpretation tasks should be included in a comprehensive evaluation of topographical maps for aircraft navigation.

Route planning tasks are relevant to all forms of aircraft operations by both visual and instrument navigation, yet map assessments have so far been concerned only with the accuracy of navigation in relation to the intended route and not with the efficacy of the choice of flight plan. Route selection tasks have been used in the assessment of road speed maps (Morrison[653]). A series of studies by Silver, Landis and their colleagues at the Franklin Institute Research Laboratories, using military logistics game maps, has developed an index of display effectiveness, known as the decision quality metric (DQM). The DQM was related to the amount of profit subjects made using displays in a trucking game, and experiments showed it to be sensitive to cartographic factors such as colour and information density (Silver et al.[562]; Silver et al.[512]; Landis et al.[513, 780]; Landis et al.[193]). Although the DQM used in these studies is not directly applicable to aircraft operations, the concept of measuring decision quality based on a realistic costs and benefits analysis is potentially useful. The costs and benefits of alternative flight-plans could be analysed in terms of operational criteria such as flight time, fuel expenditure, numbers of turns, visibility to enemy forces, threats encountered, etc.

In selecting tasks for assessing maps, the researcher would appear to have two alternative strategies. He can either use a subset of tasks that are representative of what users actually do in the "field", or he can devise tasks to measure basic map reading skills that underlie operational activities, such as search, identification and recognition (Potash and Jeffrey[778]). The first approach may be closer to real-life and have greater predictive validity, but the major difficulty is that the measurement of performance with aviation maps in the field is often impractical. Simulations may not be entirely representative, and may produce misleading results. Realistic tasks are often complex, involving other non-map reading skills and abilities which may mask small effects due to map variables. The second approach is more concerned with the ability to obtain information from the map rather than what is done with the information. Validity in relation to operational requirements may be low, but a more direct assessment can be achieved of how well information is extracted from the product.

While having a simple measure of task performance is convenient and seems elegant, it can be justified only if it makes sense in terms of operational requirements and tasks. It must have an operational counterpart. If a map aids the speed at which a task can be performed at the cost of inducing inaccuracy, there is no benefit in obscuring both of these trends by the quest for a single measure which may show neither. Nor is it permissible to choose tasks because they are simple to measure rather than operationally relevant. Where single measures can validly be used to assess the performance of a task, then they should be, but they should not be imposed if they would oversimplify or obscure trends or findings. In research on aviation maps, the practical usefulness of findings must always be considered. Research on other maps

may not have to be so concerned about this, but it is rare to encounter a study where the results are claimed to have little practical value (Wright[779]).

Choice of Experimental Material

Even when suitable tasks for assessment have been chosen, the findings depend on the selection of experimental material. This is more difficult for maps than for most information displays, because the visual variables interact so much and because experiments seek findings that can be generalised beyond the material employed. Many standard experimental procedures cannot be followed with maps, because of the nature of maps. The information surrounding any designated position on a map is unique. No two designated positions can be presumed to be equivalent. If the same map position is presented to a subject more than once during an experiment, he is unlikely to respond to it in measurable terms on subsequent presentations in the same way as he did on its first presentation when it was unfamiliar to him. These constraints rule out the normal experimental techniques of replication and parallel forms for demonstrating that the finds are reliable and not an artefact of the chosen material.

One stratagem is to express the findings not in the form in which they are obtained, but in more general concepts, and to demonstrate that the findings derived from a variety of experimental material remain coherent and unified when so expressed. It then becomes possible to adopt some experimental methods, such as using material in parallel forms, by describing each item in terms of the general concepts (Taylor and Hopkin[151]). The range of material is also expressed in general terms, such as an index of cartographic information density. The same measure can be adapted to numerous maps – all topographical maps at a given scale for instance – and comparisons made between maps to explore, for example, the relationship between amount of displayed information and graphic form (Shaw and Maclagan[630]).

There can be problems in ensuring that the examples of material selected for study encompass the whole range of available material and are representative of it. If very large quantities of experimental material are used, this problem may be resolved simply by ensuring that the specific examples of it are selected by a random process. However it may be impractical to conduct such a large experiment, and the material therefore has to be deliberately planned to be representative. Subjective selection of material may depend on intuitive processes of unproven validity. Some additional evidence is therefore needed, in the form of conversions of selected items to general concepts, independent assessments of them by others, or statistical tests for bias. It is advisable, as far as possible, to provide positive proof that items are truly representative of the whole, rather than rely on subjective claims.

Not all assessments of maps require representative material. The material must always be chosen to answer the question posed. A requirement to demonstrate the feasibility in principle of a particular map function may need only simple material; until feasibility has been demonstrated, the time and effort required to compile representative material may not be justified. A requirement to establish the limits of performance may need complex experimental material only, if the practicality of simple material has already been established. A requirement to test a high specific hypothesis may need material pertinent to that hypothesis, but not necessarily representative of the whole map. A requirement to explore in detail a particular circumstance known to lead to difficulties may need material unrepresentative of the whole map, but emphasising the particular circumstance such as a type of error, delay or confusion. A requirement to study the effects of a specific cartographic feature such as map boundaries may need experimental material which emphasises them (Laymon[305]). The general principle is to fit the experimental material to the question. It is essential that the interpretation of the findings is also confined to the question, and they are not claimed to apply more generally than the experimental material can support. The temptation must be resisted to use whatever experimental material happens to be readily available, without considering if it is appropriate or representative, or how it could be improved.

The map characteristics which have most influence on map assessments have not yet been identified, listed and weighted. They obviously depend on the operational requirement, on the tasks, on the map reader, on whether the assessment is by performance measures or subjective assessments, and on the specific measures chosen. In so far as these critical map characteristics are known, findings should be interpreted in relation to them, and experimental material checked against them to assess how representative or biased it is likely to be. How far the results of assessments are an artefact of the experimental material is difficult to establish, but the assumption must always be that they may be, until contrary evidence can be adduced. In the meantime, every effort must be made to avoid interpreting specific findings as general ones.

The rationale for choosing experimental material must always be clearly stated, to allow informed judgements of how applicable the findings may be. The nature of maps, and of most collateral material, encourages the facile generalisation of conclusions because the relevant variables can be so difficult to define. The solution is to take every initial precaution in selecting experimental material to ensure that findings can be proved to generalise as far as they are needed, rather than to trust or claim that they do generalise but be unable to prove it.

14d LABORATORY STUDIES AND ASSESSMENTS IN OPERATIONAL ENVIRONMENTS

Almost all human factors studies in aviation share the problem of establishing the nature of the relationship between findings in the laboratory and under operational conditions. Scientific methods of investigation require rigorous experimental designs with controlled and independent variables, data gathered and analysed in accordance

with a fixed experimental protocol, and findings which must not have more than one interpretation. None of these conditions can normally be met during flight, yet the laboratory studies have no practical significance unless their relevance to operational settings can be demonstrated. The problem is particularly acute with maps, because of their visual complexity and the multiplicity of tasks which require map information.

Chapanis[112] listed the main reasons for caution in applying laboratory findings to real-life.

(1) There are far more independent variables in real-life than in the laboratory. Conclusions obtained by studying only a few variables in the laboratory may be contradicted in real-life by factors not studied or interactions not recognised.
(2) Bringing a variable into the laboratory changes its nature in ways which are uncertain.
(3) The importance of the variable chosen for study in the laboratory may in real-life depend mainly on its interactions, and the residual effects demonstrated in the laboratory, though precise, may be so small as to lose their operational significance.
(4) The dependent variables measured in laboratory experiments are chosen for their convenience in the laboratory and not for their operational relevance.
(5) The variables are often presented in unrealistic ways in the laboratory.

Laboratory findings on search or identification tasks, which define basic human limitations, may be applicable generally, although it is still necessary to have common concepts in terms of which real-life and laboratory data can both be expressed (Davies[666]). Laboratory studies may be effective for permitting an appraisal of physical variables and their interactions (Boynton and Bush[668]). A quest for more sensitive and efficient measures often lies behind attempts to derive more controlled methods of assessment (Fenwick[781]), although finding a sensitive measure will not thereby bestow importance on a variable which is obscure or has effects which are very small. Nor will such effects matter if a gross effect has been ignored: details of the design of an emergency chart are of little consequence if it cannot be consulted in an emergency because it is part of an unwieldy manual (Bowen and Gradijan[382]).

Simulation is often used in aviation, hopefully to combine the advantages of laboratory studies and of operational tasks in making assessments. As a technique, it also has the potential to combine the disadvantages of both, if not used correctly. In simulation, realistic task variables can be controlled, experiments can be replicated, and many individuals can be presented with identical tasks. Procedures which are difficult to study in real-life, such as matching photographs and maps during a bombing run, can be examined, and their reliability assessed (Daniel et al.[54, 55]). But simulation has the disadvantage that its findings may have to be related both to laboratory studies and to real-life flight, and in some respects it may constitute a third assessment technique, rather than bridge the gap between the other two. While aspects of the physical environment such as turbulence may be simulated in a moving base simulator, findings such as no fatigue, continued alertness, consistent learning, and a maintained level of task performance under all conditions may raise more questions than they answer (Soliday[782]). The studies of Lewis and his colleagues (Lewis[66]; Lewis and de la Riviere[360]; Lewis and Anderson[355]) in a low speed aircraft and in a helicopter encountered the real-life problems of unexplained effects and potentially dangerous events, but considerable confidence could still be placed in the validity of their findings for low speed low level flights.

McGrath and his colleagues used a variety of methods during their experimentation on aviation maps, and emphasised the need to validate findings. They developed a film method for simulating low level flight which they believed to be a valid simulation of the visual experience (McGrath and Borden[317]), and, on discovering that it presented a very difficult task, modified it and demonstrated that it improved geographic orientation in pilots in a flight simulator (McGrath et al.[318]). They developed an analytic technique for selecting relevant features for portrayal on a map, and validated it by demonstrating that an experimental chart incorporating the selected features enhanced the maintenance of orientation during sorties in a flight simulator (McGrath and Osterhoff[325]). They established a method for obtaining data on navigation performance from operational sorties by requesting pilots to recall and record after their flight designated aspects of their performance (Borden[323]), and validated this measure by flight tests which enabled the true and recalled performance to be compared (Borden and McGrath[324]). Much training in map reading skills is acquired informally during flight, and some of these validated findings could be used to suggest more effective training methods, particularly in the key task of visual referencing (Borden[443]). An example of the integration of techniques was provided by Anon[783]; operational aspects of cartography were evaluated by an analytic technique; a series of flights was conducted with a variety of navigation aids and information; the roles of maps were identified; the cartographic information which would be required in future was then established by flight simulation methods.

Assessments may be handicapped by limited access to essential support. Fruitful research and evaluation of aviation maps are likely to require laboratory facilities, flight simulation, aircraft sorties, and cartographic production facilities. This last requirement has often proved the most difficult to meet. Professional map production effort is in short supply, and much human factors research on cartographic problems has not in fact used professionally produced maps. It is generally essential to do so to obtain valid findings. Any proposed solutions to mapping problems must be capable of production within cartographic, photographic and printing technology. Research and evaluation therefore tend to become more interdisciplinary, with the value of the contribution from each discipline being dependent on the contribution of others. It is essential that one contribution, normally but not necessarily by a human factors specialist, should include a thorough understanding of the techniques of experimental design and analysis. This is because the findings from many evaluations and assessments reported in the literature have been seriously compromised by deficiencies in

experimental planning, and particularly by a failure to appreciate that measurements of task performance are influenced by numerous extraneous or interacting factors, apparently unconnected with the task itself. Factors that may influence findings include the effects of learning, of individual differences, of the sequences in which experimental conditions are examined, and of various tactics for balancing or randomising factors which could interact. The ways in which they may do so must be fully understood before the findings can be interpreted correctly.

14e THE DERIVATION AND VALIDATION OF QUANTITATIVE MEASURES

It is not possible to provide a definitive list of the measures which should be used to evaluate a map. Various measures have been proposed for the purpose, and numerous theoretical concepts have been considered. McGrath[316] concluded that experimental data to explain the causes of disorientation or to re-establish orientation did not exist. Some progress has been made since then, but much of the research needed to provide quantitative assessments of map efficiency has still to be done. Empirical measures may be used to check that a display does in fact fulfil its intended functions, but these do not show whether it could be improved, how much better it could be, or whether a different display could be equally effective. Valid quantitative measures are needed to answer such questions.

An attempt to derive and identify dimensions of visual displays relevant to their usage was made by Siegel and Fischl[208], using multidimensional scaling techniques. Statements covering the seven identified dimensions were subsequently scaled for favourableness and then arranged in tetrad forced choice format for validation as an instrument for visual display evaluation (Siegel et al.[784]). The seven factors were:

(1) Volume of material deployed.
(2) General display format.
(3) Differentiation of signal from noise.
(4) Ordering signals according to a meaningful structure.
(5) Determining relationships.
(6) Integration of the meaning of what the display portrays.
(7) Intellectual processing for decision-making.

This last factor appears to be related to the concept of decision quality, proposed by Silver et al.[512] as an alternative measure of display effectiveness to the traditional ones such as search and accuracy. After further evaluation studies, Landis et al.[780] recommended research to establish the usefulness of display quality as a practical measure, having shown that measures of information assimilation cannot fully assess display effectiveness because they take no account of display quality (Landis et al.[513]). They claimed that, using multidimensional analysis of rating scale assessments to define display effectiveness and to build a regression model, the effectiveness of display could be assessed without further empirical data from a testing situation.

Multidimensional scaling can be used to discover the factors which determine the perceived similarity of different shapes and forms (Kunnapas et al.[551]). Different methods give similar solutions, which help to confirm their validity (Lund[785]). The multidimensional scaling method can also be used to estimate similarity directly (Waern[786]). A similar technique, principle co-ordinates analysis, has been used to identify the dimensions of 1:250,000 scale maps for low altitude high speed flight (Taylor[222]). Studies have been conducted on a large number of psychophysical variables pertinent to cartography, generally treating each variable in isolation and attempting to compensate for known vagaries in subjective assessments.

In the pursuit of valid methods of assessment, many psychological measurement techniques have been applied to maps, but none has proved sufficiently promising to become generally accepted. Stringer[595] attempted to test the readability of large scale planning maps, which differed in colour and in amount of base information, by using repertory grid measures derived from personal construct theory (Kelly[787]; Bannister and Mair[788]). The results were influenced by colour but not by base information. Stringer[789] suggested that maps for functions such as the collection of public opinion cannot be evaluated by experimental methods, and that much evaluation work on maps has viewed the role of maps too narrowly and concentrated far too much on the effects of single variables.

Valid assessments may be expressed in information theory concepts, if map reading is viewed as the transmission of cartographic information. Dornbach[127] analysed the map as an information display system, and Ratajaki[466] derived a formula related to the effectiveness with which cartographic information was transmitted. Balasubramanyan[254] analysed numerous factors which contributed to the utility of the map for storing and transmitting information, and Sukhov[475] presented formulae, based on information theory, for testing how uniform the processes of cartographic generalisation were on a map. Gokman and Meckler[790] also derived formulae from information theory, their intention being to compute qualitative aspects of the thematic content of maps. Taylor[111] showed "that not only the input (stimuli) in a cartographic communication system are amenable to analysis through information theory, but that the output (responses to stimuli or the results of map reading), can be analysed to assess the effectiveness of the communication process". Taylor showed that the concepts of information theory permitted a more sensitive measure than percentage of correct identifications, by including in the measure the effects of system noise and of information lost. He could see no *a priori* reason why the technique should not be extended, and it offers promise as a valid and practical measure suitable for map assessment (Board and Taylor[458]).

141

Eye movement recording has often been tried with maps or map-like material, though it can lead to ambiguities in interpretation and can generate large quantities of data which usually must be reduced with the aid of computers. Eye movement recordings can be related to numerous dimensions concerned with the visual prominence, significance, familiarity, rarity, and coding of stimuli (Gould and Dill[791]). Models based on eye movement recordings may account satisfactorily for search performance with comparatively simple stimuli, but fail to do so with stimuli as complex as maps, as Williams et al.[256] showed. There are large individual differences in eye movement patterns while map reading, and Jenks[199] pondered on how these were influenced by memory, and whether the map-reader's image corresponds with that of the cartographer. There is more map information stored in the memory than can be reported verbally. Attention influences eye movements, but Weitzenhoffer and Brockmeier[792] claimed that to determine the extent of this influence it is necessary to measure eye movements with the eyes open and with them shut. A comprehensive discussion of the relations between eye movements and psychological processes has been provided by Monty and Senders[793]).

Legibility seems a form of assessment which could readily be validated, but it is not clear how the concept in its psychological sense should be applied to maps, since neither of the traditional meanings of legibility distinguished by Poulton[564], rate of comprehension and rate of skimming for words, seems appropriate for map reading without some modification.

Some assessment problems are associated with the validity of assessments obtained in flight. In certain respects, these measures should be more valid than others, being obtained under real operational conditions of map use, but in other respects their validity is uncertain because it is difficult to identify all the factors present, establish their relative influence on map reading, or prove that they would remain applicable under changed circumstances. A further problem of validity arises when performance measures and subjective assessments of a map are in conflict (McGrath and Osterhoff[325]; McKechnie[306]).

A more satisfactory validation method is to derive criteria for improving map reading performance, produce an experimental map based on those criteria, and prove that the experimental map is better than the original one which did not meet the criteria. This approach was followed by McGrath and Osterhoff[325] who were attempting to improve geographical orientation, and by Hopkin[70] and Taylor[100] who were testing the value of human factors display principles when applied to maps. Some of the experimental methods for evaluating maps were reviewed by Murrell and Hopkin[763] though they were not willing to gauge the probable validity of alternative measures.

In many instances of map evaluation, investigators have been so impressed by the difficulties of obtaining quantitative measures and of generalising the findings, that they have been overwilling to presume that the findings are worth generalising and the measures worth obtaining. As a result, the worth of many measures, even the commonest ones, is largely a matter of speculation. Most chosen measures are plausible and have some face validity, but the true validity of many of them has never been established, and how circumstances affect validity is not known. Yet in the few instances when validity assessments have been attempted the results have suggested that most measures are stable and consistent enough for their validity to be demonstrated, and hence for their worth to be assessed. Meanwhile, spurious findings may be obtained because of the almost universal presumption of validity in measures which have never been adequately tested.

14f QUALITATIVE AND AESTHETIC FACTORS

Users have likes and dislikes about maps, and form attitudes about them. The ways in which they are willing to try and use a map may be greatly influenced by their attitudes towards it. The attributes of a map which engender favourable attitudes towards it may have no connection with its efficiency. Because of its appearance, it may be accorded an undeserved authenticity and a level of accuracy which is spurious. As Wright[16] put it; "an ugly map is less likely to inspire confidence", but what cartographer would deliberately make an ugly map in order to hint that the user should not place too much trust in it because its sources are suspect?

Most people seem to have favourable attitudes towards maps. Laboratory experiments with maps do not usually encounter a shortage of volunteer subjects, as experiments on dull topics frequently do. Rather the problem is to hold the subject's attention while explaining what is required of him, since as soon as a map is placed before him he has a compulsion to pore over it. Which attributes of the map exercise this fascination has been a source of much debate but no definitive study; if they could be identified perhaps they could be applied to other kinds of display. Numerous techniques might help to answer this question, but the visual interactive effects and the complexity of displayed information might themselves be the main sources, rather than any more readily quantified visual dimensions. A concept such as visual balance is an attractive one.

Because the cartographer strives to give the map a pleasing appearance, his success in achieving it may be a matter of personal taste rather than reflect the usefulness of what is portrayed. Too much stereotyped mechanisation in map production was believed to be counter-productive by Carmichael[647], who contended that artistic effects could be achieved by subtle rather than extravagant usage of colour on the map. The conclusion of Cuff[600] tends to support this view, for colour could have such a potent influence that it could readily become ineffective unless carefully controlled. Saunders[622] suggested that the effectiveness of colour on maps could be judged by its pleasing appearance, its appropriateness for the purpose, its unifying attributes, its variety, and the interest it aroused, most of which are

aesthetic qualitative factors. Colour is one of the main determinants of the aesthetic judgements made about a map, but most identifiable factors can be claimed to exert some influence in so far as changes in them induce changes in aesthetic judgements of the map. The regularity of patterns is a relevant factor, and so is the success with which the items in a set have equal-appearing intervals between them. Sometimes a flat tone is preferred to any visible texture (List[794]). In three dimensional mapping, aesthetic factors may assume even greater importance as a means of generating required visual impressions (Jenks and Steinke[735]).

The application of ergonomic principles to maps (Hopkin[771]) may minimise the importance of aesthetic factors, since ergonomic display principles are usually promulgated as functionally efficient rather than aesthetically satisfying. Although there is some evidence that subjective impressions of information density may be a major determinant of aviation map preferences (Taylor[222]), nevertheless density is usually specified in objective rather than subjective terms (Taylor and Hopkin[108]). It may nevertheless be as important to make the portrayed information appear to be less dense, as actually to reduce its density. The emphasis on quantitative measures implies that such options tend to be neglected, but they might succeed.

Whereas judgements of the functional utility of a map are made after trying to do one or more tasks using specific items of information on it, aesthetic judgements of the map are made by viewing it as a whole, and perhaps before using it. Although eye movement recordings may demonstrate that the map is being scanned, aesthetic judgements have not been made about the sequence of fixated items. It is often much easier to identify the factors which mar balance and harmony in a map than to name those which enhance them. The aesthetic problems in trying to achieve a visual effect not merely of figure and ground within the map, but of a background on which information is superimposed at more than one visual level (Wood[188]) have not been examined, although several visual distances can be portrayed under certain circumstances by utilising the different apparent visual distances of colours.

Evaluation of maps in aesthetic terms still tends to be rudimentary and of dubious validity. Board and Buchanan[795] commented on map assessments which do little more than state the reviewer's predilections, and they noted that aesthetic judgements are often highly questionable. However, they need not be. A consensus clearly exists on what is pleasing in a map and what is not. If the basis for this consensus can be validated, guidelines for acceptable and pleasing maps can be compiled. These are worth attaining, partly for their own sake but also because if a map is liked and engenders favourable attitudes among users, it may thereby be used more efficiently, and is certainly more likely to be tried.

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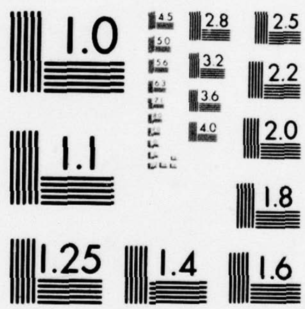

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CHAPTER 15

FURTHER MATERIAL RELEVANT TO AVIATION MAPS

15a STUDIES OF OTHER MAPS

The variety of map studies reflects the many purposes which maps may serve (Board[796]). Since there are difficulties in generalising findings from one aviation map to others, greater difficulties may be expected in generalising findings from other kinds of map to aviation maps. Nevertheless, this does not mean that, in applying human factors principles to aviation maps, nothing of value can be learned from other cartographic research. It can be a fecund source of illuminating insights and hypotheses, provided that they are treated as such, and not applied to aviation maps uncritically and without verification.

Human factors principles, and particularly the psychological principles of visual perception and information transmission, have received considerable attention from geographers concerned with map design. Research on perception and map design relevant to geographical maps has been reviewed by Board and Taylor[458]. Examples are Wood's[188] concern with depth cues and visual planes as aspects of map design, Brandes'[550] discussion of geographical and qualitative symbols, and Jenks'[797] interest in visual proportions and the principles of clustering in relation to gestalt theory. Cartographic texts (Robinson and Sale[95]; Keates[120]) usually make some reference to relevant psychological principles, if only by directing the reader to standard introductory books on psychology.

Mental Maps

Psychological interest in map reading and in the processes that accompany it has followed the vagaries of psychology in the study of conscious processes. Quantitiative assessments of mental map imagery have a long history (Elderton[798]), but it was learning theory, and its preoccupation with maze learning, that stimulated interest in cognitive mapping (Tolman[85]). With the change of emphasis within psychology, whereby the study of experience was re-admitted alongside the study of behaviour, mental maps became a respectable topic for psychological research in their own right, evidenced by the inclusion of a chapter on cognitive mapping in Neisser's[799] text. Previous authors (Howard and Templeton[91]) had pointed in the same direction. Now, mental maps are considered relevant to the study of numerous spatial/psychological phenomena in geography, environmental psychology and town planning (Stea and Downs[289]; Ittleson et al.[800]; Ittleson[288]; Downs and Stea[290]; Gould and White[82]; Canter[294]), and as a basis for development and knowledge (Kaplan[510]). Several techniques have been proposed for their measurement (Gould[295]; Howard et al.[801]). Other authors have studied the mental maps of primitive and remote people to investigate the role of innate abilities and learned skills of geographical orientation (Lynch[275]; Oatley[276]; Lewis[84]).

The main alternative to studying the mental maps of primitive peoples is to study children's, to understand how spatial orientation and map reading skills evolve, and how they should be taught. The literature on map reading by children is very large. Its starting point may be spatial orientation and concepts of direction (Smith[272]; Lord[273]), the development of map reading skills (Bathurst[802]), or determining the essentials of a good map for children (Warman[803]). Riffel[752] found that coloured photographs, and stereo pairs of black and white photographs, helped the child's conceptualisation of the map and the symbols upon it, but he draw attention to the child's difficulties in forming concepts which were not egocentric, a necessary stage in map appreciation (Riffel[264]). Children do seem to develop some of the necessary facility for abstract thought (Savage and Bacon[751]), and there is some evidence of spontaneous and untaught map reading abilities (Blaut and Stea[760]; Blaut et al.[804]). Bartz[441] contended that a new approach to map design for children was needed. The very extensive study on early map reading, which nevertheless did not lead to conclusive findings, may be sampled in the work of Fischer[260]; Plumleigh[263]; Kilman[262]; Stampfer[805]; Duhon[806]; Murdoch[265]; and Zimmer[807]. Some studies have had more specific objectives, such as understanding contours (Poh[632]) and examining children's understanding of maps in relation to aerial photographs (Hart[274]; Dale[497]).

Tactual Maps

Further evidence on mapping as an aid to orientation comes from the development and evaluation of tactual maps for the blind. Such maps may be of districts or of routes, may be static or portable, and may be spatial or verbal (Leonard[278]). One approach to studying mobility aids for the blind is to use life-size mazes (Maglione[279]). Various types of route map can assist a blind person to follow an unfamiliar route (Leonard and Newman[89]). Tactual maps for the blind have employed a series of tactual symbols, each of which is discriminable and has a meaning which can be learned and recalled. Relationships with existing tactual symbology, such as braille, also have to be checked. Several studies (James and Gill[808]; Gill and James[809] etc.) have been conducted to identify and validate suitable symbols, and

to test the mobility of blind persons using tactual maps containing them. The role of computers in drawing maps for the blind has also been explored (Douce and Gill[810]). A bibliography has been compiled (Gill and Tobin[811]). Positive or negative format, white or black symbology has been compared on maps for the partially sighted (Greenberg[812]). Although tactual maps for the blind bear little physical resemblance to aviation maps, they share the problems of the derivation of unambiguous symbology suitable for the envisiaged functions, and of facilitating reorientation if the user has become lost.

Urban Maps and Tourist Guides

Maps for the blind are generally concerned with urban environments at large scale. Among other approaches to maps of the urban environment, two are of potential interest for aviation maps because of their methodology. Stringer[595, 789] believed that experimental methods could not validly be used for such purposes as enlisting public participation in urban planning, and contended that multidimensional assessment techniques must be employed. He used the repertory grid, pioneered by Kelly[787] and developed by Bannister and Mair[788], as a measure of the comparative readability of alternative map formats. His results were sufficiently encouraging to suggest that the technique may be worth trying in other map-evaluation contexts. McCleary's approach to large scale mapping for tourist guides was based on evidence on cognitive mapping and on the effects on behaviour of differences in the map user's image of his environment (McCleary[812]; McCleary and Westbrook[814]). This variable, the user's cognitive map and his image of his environment, has not been included in studies of aviation maps and it may warrant examination. The extent to which the choice of routes is influenced by past experience is not known, nor are effects of previous disorientation experiences on mental maps and route selection. Standardised symbols for tourists' maps have been proposed by Ostrowski[815]. Whereas standardised symbology can obviously benefit the tourist in a foreign country, just as it is essential for world-wide use of aviation maps, some authors (Fisher[816]) have argued that realistic, pictorial symbology is an important factor in the success of large scale urban maps and street guides if the features shown are locally recognised land-marks. The principle of portraying pictorial land-mark symbols is well established in aviation cartography.

Relief Maps

One means of improving the user's image of the environment is to examine how alternative conventions for representing terrain can enhance the formation and efficiency of his images. Many of the possible ways of depicting terrain were described by Imhof[636] who also discussed the role of contours as an example of isolines joined equal measured quantities within the dimension of height (Imhof[817]). Various methods can be employed to provide a direct image of terrain. Tanaka[646] outlined a scheme for obtaining visual impressions of relief on maps by illuminating contours so that they gave the illusion of shading under oblique lighting. Yoeli[643] compared three different kinds of illumination to produce relief shading, and concluded that hand drawing of shaded relief gave more successful effects than photographs of relief models, because drawing was more flexible, and the appearance of hills and valleys did not depend so critically on their orientation in relation to the northwest. Jenks, in a series of studies (Jenks and Steinke[735]), examined three dimensional maps. He explained how they could be constructed by anamorphosis, and advocated their more extensive use (Jenks and Brown[162]). He offered guidelines for selecting favourable viewing positions for looking at three dimensional maps (Jenks and Crawford[818]). He applied three dimensional techniques to marine mapping by constructing a three dimensional bathyorographic map (Jenks and Crawford[819]). He expounded the role of three dimensional maps as teaching aids to facilitate the understanding of terrain depiction on topographical maps (Jenks et al.[627]). Computer drawn cartography may also permit three dimensional viewing and rotation of surfaces (Peucker[140]). The legibility of relief on topographical maps has been studied by various authors including De Lucia[645], Shaw and Maclagan[630], Hopkin[640], Taylor[402, 641], Phillips et al.[267] and Potash et al.[775].

Thematic Maps

Maps intended for specific rather than general purposes are termed thematic maps. The main criterion for testing their effectiveness is the successful communication of the information the designer intended to convey. However, the designer's intentions are not always known. Gerlach[480] listed ten factors with a fundamental influence on the effectiveness of thematic maps:

(1) Correct titling of the map.
(2) Omitting inessential data.
(3) Selecting the best map scale for its usage.
(4) Avoiding visually prominent map framing.
(5) Using white as a colour.
(6) Using legible and meaningful symbols.
(7) Minimising styles and sizes of type.
(8) Using cartograms rather than maps where appropriate.
(9) Showing dynamic changes by mapping.
(10) Designing each map to convey information effectively.

Many of these factors are equally relevant to other maps. A further factor relevant to the design of thematic maps is figure-ground ratio (Crawford[620]). The various types of thematic map, and methods for evaluating them, have been reviewed by Board and Buchanan[795] and Board and Taylor[458].

Keates[120] grouped thematic maps under the general heading of special-subject maps, and included statistical maps in the same group. These deal with statistical data, and introduce several illusory perceptual effects which can lead to misinterpretation (Clarke[255]). Problems in generalisation and in selecting class intervals for statistical maps were described by Jenks[479] and by Jenks and Coulsen[820]. Basic texts incude those of Dickinson[821] and Birch[481], and Monkhouse and Wilkinson[139] illustrate various kinds of statistical map. They share many problems with the representation of relief on topographical maps, particularly in the choice of symbology, and in the limited knowledge which users may possess about the conventions being employed.

Studies of numerous kinds of thematic map of borderline relevance to problems of aviation maps can be mentioned only briefly here. In common use are chloropleth maps, based on statistics, and depicting average values for unit areas. Muller[822] has described recent studies on them. The experiments of Rhind et al.[519] dealt with geochemical maps and the use of wind-rose symbols. Connolly[823] studied contouring on weather maps. Ratajski[498], criticising the excessive number of symbols on maps and the lack of world-wide internationally agreed standards for them, was primarily concerned with economic maps, although his strictures apply as forcibly to most topographical maps. Anderson[824] reviewed user requirements for nautical charts, and called for improved techniques in their production, particularly by applying computer methods to keep the information on charts more up-to-date. Kirby[769] has contributed a general review of the functions which maps are expected to fulfil.

Transportation and Road Maps

Road maps are the subject of continued research. The road traveller's expectations about his maps were described by Morrison[652] who noted that there was insufficient evidence to judge how well they were being met. Astley[651] also studied road users' requirements, and noted that users preferred folding maps to atlases, and often compiled their own route guides. Questionnaires have been employed to obtain views on the value of various road maps for route finding (Sheppard and Adams[770]). Experimental road maps depicting probable road travel speed have been developed by Morrison[514] and evaluated by comparing them with conventional maps for selecting the best route. Cost-benefit analysis techniques were used to judge what was best, and to show the savings which would accrue from using speed maps for route planning.

Transportation maps and tourist guides place less emphasis on spatial accuracy and more on design than do most aviation maps, because the users' requirements are very different. On transportation maps the user is mainly concerned with identifying the correct route for his journey between a given starting point and destination. Navigation between these points is either self-evident or carried out by someone else. The user needs to know to correct order of stations, staging points and intersections with other routes, but accurate information on distances, twists and turns is usually not needed and places an unnecessary constraint on the designer who is mainly concerned with providing legible symbology. It is only when the user wants to relate the transportation system to other information, such as a street plan, that spatial accuracy may be needed. This is a separate task usually carried out before starting the journey or at the end, and it should be performed on a separate map. Maps of Underground Railway Systems in cities often sacrifice spatial accuracy in favour of legibility, retaining only the general direction and positioning of routes.

In most forms of aviation cartography, accurate positioning of symbols is of paramount importance for accurate and safe navigation, and the generalisation achieved at different map scales is normally sufficient to reflect the varying need for accurate representation. Deliberate, exaggerated generalisation may be justified on perceptual grounds for some tasks, such as the identification of airfield runway patterns or town shapes, and most maps contain many examples of co-located features that have had to be repositioned to permit discrimination. Simplified representations of routes and airways are used on small-scale charts for en route radio navigation where accurate navigation is achieved with reference to instrumentation rather than map reading. Passenger information displays, global route maps etc, need not be spatially accurate and other design considerations such as legibility, conciseness and attractiveness should take preference, particularly when small scales introduce the characteristic inaccuracies of various map projections (cf. Chapter 2).

Resumé

Among the extensive cartographic literature unrelated to aviation problems, certain common themes emerge which apply to aviation maps also. Ideas of users' needs and of how maps are in fact used are generally hazy. Problems in choosing appropriate meaningful symbology are endemic to all maps. The role of computers is still in the process of being worked out, since technical feasibility has out-stripped financial resources, data storage and practical computer skills. Maps tend to show too much, in ways which are insufficiently self-evident for the user. Logical ways of integrating them with, and relating them to, other material, such as photographs and models, are still being sought. The development of map images in children and the extent to which the images can be modified, refined and changed by learning and training remain uncertain. Cartographic portrayal is still highly dependent on intuitive processes.

15b CARTOGRAPHIC ANNOTATION OF AERIAL PHOTOGRAPHS

In cartography, aerial photographs have been considered mainly as an aid to map compilation and interpretation, and as a substitute for maps where none are available (Dickinson[134]). Studies have been most concerned with the kinds of cartographic information, and the quality of that information, which can be gleaned from vertical air photographs, and, to a smaller extent, with the less severe problems of interpreting oblique air photographs. The physical properties of air photographs have been examined in some detail, particularly in those respects where they differ most from maps, and various tools and techniques for plotting map detail from air photographs have been developed. These are themes which Dickinson[134] deals with. Taking measurements of air photographs is called photogrammetry, a technique now used extensively in map making. An introduction to techniques of photogrammetry is providing by Spurr[825], and Keates[120] covers associated map production processes.

The topic of aerial photographs shares, with others which consider visual search and pattern perception and interpretation for aviation purposes, the difficulties of relating the extensive laboratory work to practical operational problems. On the whole, the basic laboratory work cannot be presumed to be applicable to real-life problems. Solutions which rely solely on such evidence may be wrong, because crucial factors present only in the operational setting invalidate the laboratory conclusions. Positive efforts are made from time to time to bridge this gulf (Morris and Horne[444]), with dubious success in that the avowals of closer collaboration associated with these efforts are generally ephemeral, and each protagonist continues on his own way thereafter, much as before. The propensity of laboratory studies to examine variables in isolation, or in highly controlled contexts, also limits the applicability of laboratory findings to operational environments where the contexts and the tasks are much more interactive and less controllable (Heath[147]). Findings such as that of Thornton et al.[258] that an individual's perceptual style, as distinct from any attribute of the visual stimulus itself, influences significantly his ability to identify targets on aerial photographs correctly, introduce further complications in assessing the validity of laboratory findings in applied contexts.

Wickland[161], dealing with new map forms, was mainly concerned with the Pictomap, which denotes photographic image conversion by tonal masking procedures. It was derived from standard photomosaics, with the addition of symbolic and alphanumeric data, and the example showed its main advantages and also its problems, such as contour elevation and variable contrast with background levels. Radlinski[826], comparing in general terms orthophotomaps and conventional maps, noted that there were no fixed criteria to define the content and format of overprinted symbology for orthophotomaps, and he suggested that intended usage should largely determine what should be chosen, although the addition of a great deal of over-printed information would not only cause clutter but would be costly and thereby negate one of the main advantages of orthophotomaps. He could not therefore cite valid evidence to provide guidance on how to make the best use of orthophotomaps. He was not primarily interested in their applications in aviation.

Hill[164, 309, 516, 434] conducted a series of experiments on the usage and annotation of orthophotomaps for military purposes. He traced two previous studies, those of Berry and Horowitz[515], and of Wheaton et al.[504]. The findings from the former seemed tenuous when subjected to rigorous statistical scrutiny, and the findings from the latter were judged to have limited applicability because of the nature of the tasks employed. Therefore Hill[309] concluded that these findings should not be presumed to apply to orthophotomaps in general.

One of Hill's first findings from his own studies was that simple linear annotation of features such as roads and railways produced significant improvements in object identification, from which he concluded that the identification of these particular features on unannotated orthophotomaps would be inadequate. It was possible to suggest other linear features prominent on the orthophotomap, such as field boundaries and hedgerows, with which the annotated features could readily be confused on an orthophotomap though not on a conventional map, on which they would not normally appear. Performance at object identification tasks was better with a conventional map than with any of twelve orthophotomaps, varied by a combination of six kinds of reprographic technique with two levels of cartographic annotation. Hill[516] employed a variety of map reading tasks, including object location and identification, terrain visualisation and height estimation, intervisibility estimates for simulated indoor map tasks, direction and self orientation, and field-to-map location and orientation, simulating map tasks in the field. Confidence and preference judgements were also obtained. These proved to be important by demonstrating that for orthophotomaps stated preferences were of no use as a guide to objective measures of efficiency.

As might be expected, performance with the orthophotomaps depended on graphic treatments, on environmental (day or night) conditions, and in particular on what the map was used for. Annotation was generally worth having in terms of efficiency, to the extent that Hill[516] recommended that "one important aspect of an orthophotomap which should receive specific attention in future evaluative studies is that of cartographic annotation". His studies were primarily exploratory rather than definitive, and succeeded in identifying topics for further study, without aiming to provide any final solutions or recommendations.

Smith[165] studied point symbols on orthophotomaps, as distinct from Hill's linear ones, but he also concluded that it took longer to extract information from an orthophotomap than from a conventional map. Leos[827] found little to choose between photomaps and conventional maps in the performance achieved with them by military users, but he also remarked on the map-task interaction whereby some tasks were performed better with one map type, and some better with another.

Some of the psychological processes associated with photointerpretation (Hempenius et al.[680]) apply to orthophotomaps, and the expectations which they generate in the user may be different from those associated with a conventional map of the same region. The distinction drawn by Gamezo and Rubakhim[628] between two kinds of imagery, dealing respectively with images of terrain in two or three dimensions or with schematic reduced elementary models of terrain, was considered by them to apply to aerial photographs, topographical maps, and imagery derived from memory or from imagination. It would be expected that such individual differences in imagery and in thought processes would not only influence the way the individual actually uses an annotated air photograph but also influence the ways in which he is capable of using it.

The difficulties of annotating air photographs for operational use reveal that many of the problems studied for a long time with conventional maps have still to be tackled for orthophotomaps. The choice of symbols and codings including colour, the selection of features for portrayal, the need to maintain adequate contrasts of annotations against the whole range of orthophotomap backgrounds, the fact that different tasks require different annotated information and therefore that a multipurpose orthophotomap will tend to become overcluttered with diverse annotations – these present problems which cannot be resolved adequately on existing evidence. Insufficient research has been done on orthophotomaps, and the human factors findings about displays must not be presumed to be applicable to them. Symbols and alphanumerics suitable for conventional maps cannot be applied to orthophotomaps without vertification, and probably cannot be applied validly at all, since orthophotomaps and conventional maps differ so much in their coding requirements and in their conditions of use.

Standard procedures should suffice for evaluating orthophotomaps to ensure their effectiveness. A job analysis is the best means to ascertain what annotation is necessary. Display and coding principles can be used for the detailed formulation of appropriate symbology. Evaluation is necessary to verify the operational efficiency of the resulting annotation. Most of this work has yet to be done.

15c THE PERCEPTION OF COMPLEX PATTERNS AND FORMS

There is a very large literature on the perception of patterns and forms (shapes), much of it testing theoretical concepts. Its extensiveness owes more to the ease of conducting experiments on pattern and form with a minimum of resources than to the scientific importance of the topic. Many earlier findings have now been discredited, and many theories discarded. The simplicity of the experimental material proved to be deceptive. So many interacting factors influence the perception of patterns and forms that predictions of performance can be difficult even with the simplest material.

Maps are complex visual patterns: the study of patterns and forms should therefore be relevant to maps. The longstanding relevance of pattern perception to many military procedures is reflected in a series of monographs relating the two (Hake[79]; Wulfeck et al.[101]; Weiss et al.[211]; AGARD[212] etc.). Map reading is often classified as a pattern recognition problem but few studies of pattern and form perception are designed to produce results that are directly applicable to map reading problems. There are three main reasons why the numerous laboratory findings have proved to be generally useless and often misleading in practical applications such as maps:

(1) Real-life conditions cannot normally be replicated in the laboratory, and laboratory conditions are seldom encountered in real-life: perhaps vigilance tasks demonstrate this most clearly.
(2) Experiments conducted to test theories do not seek to include variables of practical relevance, so that if the theory is shown not to be general, little of practical value remains: there is no universally accepted theory, and new concepts and frameworks are still being introduced (Gibson[81]; Haber[828]).
(3) Almost all the findings about patterns and forms are now known to be highly task specific: the concept of an optimum pattern or form for a multitude of tasks has been discredited. No single shape is more discriminable than all others; no simple index of discriminability has been found; almost all findings are not absolute but relative, critically dependent on environmental conditions, on tasks, on the visual context, and on attributes of the individual. These conclusions, at least, probably remain true for maps.

Theoretical studies may or may not employ forms with intrinsic meaning: practical contexts almost invariably require meaningful forms which can be readily and unambiguously verbalised, whether they are simple familiar shapes, such as circles or triangles, or shapes for which a meaning has been learned, such as a swastika, the four suits in a pack of cards, or alphanumerics (Hitt[239]; Smith and Thomas[240]; Smith et al.[241]). Theoretical studies are often concerned with simple forms at or near the visual threshold and errors are deliberately sought as a measure of performance. Applied studies can never tolerate high error frequencies, and seek to establish the conditions to be fulfilled to ensure that errors will be negligible. These different kinds of study may lead to different findings and there is no reason to suppose that studies of simple visual forms must necessarily yield evidence relevant to maps, with their complex symbology, backgrounds and contexts.

The complexity of form perception can be gauged from a text on the subject (Zusne[206]), or from reviews of the relevant factors (Hopkin[80]). Some concepts can cause confusion. Zusne and Michels[829] found that their notion of geometry was equated with regularity and with familiarity by their subjects. Sleight[830] found that in a sorting task the discriminability of a form was not closely related to its simplicity as a gestalt. Figure-ground relationships influence form

perception (Weaver[831]); therefore identical forms in different parts of a map may not always be perceived as the same. A complex spatial integration mechanism may operate when forms are superimposed (Bagrash et al.[832]). Dimensions within a form may not be perceived as equal, though they are (Sleight and Mowbray[833]), nor are the quantitative physical relationships between length, area, and volume correctly perceived and interpreted (Ekman and Jones[180]). When verbal labels have to be learned for a set of forms, as in maps, this may improve their differentiation and aid the development of a categorising process (Hake and Eriksen[246]). The more the information needed to specify a particular form, the more probable it becomes that it may be confused with others (Hochberg and McAlister[834]).

Baker et al.[835] asked subjects to search for specific target forms embedded in complex arrays of varying resolution. Search time increased with the search area to be scanned, and both time and error scores increased as a function of the difference between the resolution (blur) of the reference (briefing) target and that of the target embedded in the display. Increased target size reduced errors and times. The important finding was that the absolute resolution of the forms was of little significance, as long as the resolutions of the briefing material and the search display were matched. This has obvious relevance to the provision of radar prediction strips to facilitate in-flight radar interpretation; for radar map matching it would seem to imply that as the map is normally a high resolution image the resolution of the radar imagery should be correspondingly high. Thurmond and Alluisi[836] concluded that the effects of task variables were large enough to place serious limitations on the generality of studies of visual form perception.

Form recognition studies are usually concerned with the recognition of specific features, whereas pattern recognition involves the perception of some overall configurations (McCormick[106]). However, the distinction between a complex form and a simple pattern is not clearly definable. Compared with a form, a pattern is generally more visually complex. less readily labelled as a whole, less easy to specify, and more likely to possess internal visual texture. Tasks with forms usually differ from tasks with patterns, since the form is treated as a gestalt, but the pattern is examined for its internal details. Thus, findings about forms seldom generalise to patterns, or vice versa, because of task and other differences.

Sekular and Abrams[237] showed that the concept of visual sameness was task dependent. If whole patterns had to be matched, a kind of gestalt processing could be used, but a different strategy based on serial processing was necessary to find patterns with the same elements in. The size of the set which includes a particular pattern influences the time taken to discriminate it (Clement and Varnadoe[538]), but even when both task efficiency and instructions require single element processing of patterns, subjects may nevertheless be unable to process them except as visual entities (Clement and Weiman[539]). It is a mistake to presume in experiments dealing with visual patterns that co-operative subjects will always be able to obey instructions.

Bush et al.[217] simulated map matching with radar or infra-red displays in a pattern matching task which required subjects to search four comparison patterns for a specified standard pattern. Response times were quicker when the standard pattern was less complex than the four comparisons and slower when the standard pattern was more complex than the comparison patterns. This means that when a particular target (standard) pattern is being sought in a dynamic visual field or visual display, generalised briefing aids such as maps are likely to be better cues for search than highly detailed material such as aerial photographs which are at least as complex as the comparison scene. One explanation of this finding could be that detailed targeting material places a larger perceptual and memory load on the observer, than generalised aids, such as maps. Maps display only the most salient topographical features and omit much redundant and irrelevant detail. Maps reduce the amount of processing of the targeting material that has to be carried out by the observer, they reduce individual differences in information attended to, and they classify the information into readily remembered topographical categories by cartographic coding. Thus, pictomaps, orthophotomaps and other forms of image-based product generally prove inferior than line-maps in comparative assessments using realistic field tasks, and substantial cartographic annotation is needed to produce near comparable performance (Wheaton et al.[504]; Hill[516]). McCormick[106], referring to Bush et al's experiment, incorrectly reported that performance was superior when the target pattern was more complex than the four comparison patterns. Consequently, his conclusion that adding information to maps (i.e. increasing map scale) is more deleterious to performance than additional information in the aerial view (i.e. reducing altitude) does not readily follow from the original results, and should be treated with caution.

A satisfactory means of specifying subjective pattern complexity has proved to be as elusive as a satisfactory index of subjective density of cartographic information on a map. Payne[614] proposed than an objective index of complexity, based on sequences of elements within the pattern, could be equated with subjective complexity, but when he tested this hypothesis he found that subjects did not use the same criteria: some used only the main psychophysical variable of line segments, some used higher order concepts of symmetry and recurrence, and some used both. Cabe[615] equated patterns for statistical information content and showed that they were not judged to be equal in complexity. Kantowitz[537] concluded that concepts of pattern, as measured by discrimination and by recognition, were not a simple function of information content. Fitts and Leonard[837] were concerned with pattern recognition, and examined the effects of learning, redundancy, complexity, orientation (Taylor[287]), and visual noise. French's[838] finding that target recognition is impaired by increasing the complexity of visual noise may be applicable to maps, but needs confirmation.

Self[839] criticised the detection-recognition dichotomy as an over-simplification. Contrast may influence detection time rather than the probability of detection. Contrast, and even resolution, may be unimportant with certain tasks and instructions. The target background is a critical determinant of detection time, as is the subjective probability estimate of the target's likely position. As a result, initial search patterns may be very inefficient and detection or recognition prediction models must be complex to be of practical use. They must include some reference to the classes

of objects chosen to be fixated during search, and the criteria, such as colour, guiding the sequence of fixations (Williams[201]).

For certain search tasks, colour coding is beneficial (Smith[580]); for others it may not be (Smith[587]). Stereoscopic acuity may be poorer for coloured targets which tend to be seen at different visual distances depending on their colour (Middleton and Parker[840]). Colour may not provide a remedy for decreases in legibility associated with overprinted information (Smith[542]), and the effects of colour interact with those of other coding dimensions (Smith and Thomas[240]) and are very task dependent (Christ[572]).

Williams[200] suggested that target location during search depends mainly on target conspicuity as it affects scanning, and on rate of presentation of the display to be searched. These findings are compatible with those of Enoch[526] on the effects on search of image degradation, and of Richman et al.[449] on time limitations for searching. Their experiments, and others, were summarised by Enoch and Fry[197]. Symbols vary in their recognisability when other information has been superimposed over them (Williams and Falzon[543]). Symbol recognition is impaired as display movement increases, and impairment may occur first with vertical movement (Williams and Borow[671]). The rate at which impairment occurs must depend on the detailed perceptual nature of the moving displayed material and of the target. When the patterns to be searched are primarily pictorial (e.g. Lipkin and Rosenfeld[730]), it is insufficient to treat the process simply as a learned visual language (Hochberg[841]). The problem of how someone learns to see pictures in a complex one, and any models of the process, for purposes such as studying and understanding photointerpretation, must account for such factors as expectancies, methods of observation, filtering, and checking (Hempenius et al.[680]).

A few studies of maps have contributed towards knowledge of patterns and form perception. Jenks[797] has examined the perception of clustering and of proportional increments in the size of map symbols. Dent[556] examined map reader's generalisation of geographical shapes in order to understand how the meaning of cartograms could be conveyed more effectively. The studies of map symbols by Kaponen et al.[29], Lichte et al.[56] and Ekman and Junge[180] have been acknowledged as contributions to the literature on symbology. Olson[518] has applied the concept of similarity to maps. Clarke[255] and Makowski[573] have dealt respectively with illusory and aesthetic attributes of maps. Many other examples could be cited. Just as caution is necessary, however, in suggesting that findings from studies of patterns and forms may be applicable to maps and should influence their design, so it is necessary in considering whether these findings about map symbology may apply to other patterns.

15d PRINCIPLES OF GOOD DESIGN

In so far as cartography may be considered as both a scientific and an artistic endeavour (Yanosky[574]), good design is aligned with art rather than science. Design in cartography is sometimes equated with the artistic impression of the whole map, and sometimes used to refer to graphic design or attributes of symbology. Robinson[606] complained that the undue emphasis given to the artistic qualities of maps had led to excessive reliance on subjective aspects of map design, to the neglect of objective visual tests of the functional utility and efficiency of putative design principles. Crawford[842], who developed this theme, noted that progress towards objective map design principles had often been confined to designs for specific symbols, at the expense of the design of the whole map. There has sometimes been too much emphasis, in cartographic training, on the technical details of map production, and insufficient exposition of the nature of graphic communication and of the role of design in facilitating communication processes.

Attempts have been made to provide cartographers with some basic instruction in the principles of graphic design (Ferens[843]), and to relate map design principles to the processes of visual perception (Wood[188]). Choha[844] had to conclude that the graphic arts had failed to rise to the challenge afforded by the design of efficient aviation maps and charts, and, despite the technical developments in graphic design which he outlined, there seemed to be no major effort to convert graphic design from an art to a science.

Easterby[493] distinguished the role of the experimental psychologist, who seeks to understand the processes used by observers in assimilating information from visual stimuli, from that of the graphic designer, who ensures that certain stimuli are effective at conveying information. In a subsequent paper (Easterby[557]), he examined the proliferation of graphic symbols, and concluded that efforts at controlling and manipulating symbology in order to convey meaning and information had not been successful. He noted that graphic design as a discipline is in its infancy, and therefore it is unreasonable to expect pat solutions to design problems. In designing symbols, an optimum balance has to be struck between meaningfulness and pictorial quality.

One possible approach to design problems is to examine how people learn to see symbols, which is much more practicable than trying to study how they learn to see whole pictures or whole maps (Hochberg[841]). This approach may be extended to study how meaning is imposed on symbols, and how judgements are learned of what constitutes a good or pleasing symbol. Almost certainly, in view of culturally determined aesthetic preferences, judgements of good design are a matter of learning, mediated by judgements of aesthetic quality which are themselves culturally determined and hence l[illegible]d. Relevant factors may be figural goodness and figure-ground relationships (Hochberg and McAlister[834]), and pe[illegible]al clarity (Dodwell[625]). Design must be related to function, and in considering, for example, the design of typefaces, it is necessary to consider the various functions of map lettering (Bartz[194]). In many cartographic contexts, the way colour is used has a dominant influence on judgements about the map design (Makowski[573]; Yanosky[574]).

Mental images of maps (Gould[295]) might be expected to have some influence on judgements about map design, in that a good design might be one in conformity with mental images and subjective thought processes about maps. The influence of mental imagery on concepts of good map design does not seem to have been examined. Studies of the discriminability and meaningfulness of symbols do not normally take cognisance of principles of good design. It is serendipidous if symbols selected for their discriminability also please. The problems of quantifying and assessing the factors which contribute to good design, and of establishing how universal the concepts of good design are, have still to be solved in relation to maps.

15e PSYCHOLOGICAL THEORIES

Psychological theories are potentially of great value, but actually of very limited use, in relation to maps generally, and to aviation maps in particular. It would be reasonable to suppose that theories of perception, of learning, of attention, of memory, of information processing and of communication would all be most helpful, and that other more specific theories, such as signal detection theory and personal construct theory, could provide useful frames of reference and insights on how maps should be designed, or used, or evaluated. But the fact remains tht the practical assistance to cartography afforded by psychological theories has been negligible; it therefore behoves the psychologist to account for this failure, and to indicate the circumstances under which psychological theorising could make a worthwhile contribution.

Some of the explanation lies in the methods of theorising. Psychological theories are built on evidence which is generally obtained in the laboratory and not in practical work environments. The relevance of psychological theories to practical situations is therefore curtailed by the same factors which Chapanis[112] identified when considering the relevance of laboratory studies, and which can be summarised as an insufficiently close approximation to real-life. However, the litter of discarded, discredited, abandoned, or inadequate psychological theories points to a deeper malaise, which has led to critical examination of theorising as a process, and to a questioning of the intentions of psychology as a discipline.

Psychological theorising seems wayward, to the extent that it deliberately eschews practical evidence from real-life environments and relies on data gathered in articifical laboratory settings, thereby posing the dilemma that any theory will be applicable to real-life environments only if their commonality with the laboratory can be demonstrated. Psychological theories adopt an analytical and simplistic view of behaviour, with the result that theories deal not with man's entire behaviour pattern but with fragments of it, so that concepts like map reading or visual balance are too complex for many theories to handle. Theories generally give an inadequate account of both the unity and the continuity of behaviour.

Theoretical formulations which specify man in the same concepts as machines saddle the psychologist with the logical problem of having to explain, within such formulations, why people and machines are not constantly confused with each other, and they reveal the inadequacy of the formulations by demanding recourse to concepts outside them to explain something so simple. In the practical world men and machines are very different behaviourally – in speed, in errors, in mobility, in data handling, in innovation etc. – to the extent that communication between them poses major difficulties. Consequently, any theory which describes man and machine using the same concepts must be out of touch with many practical problems. This is not a discussion of the age-old puzzle of man as wilful or deterministic, having a free will or not. It is to state the practical point that if man is himself a machine he is not like the machines which men make, and psychological theories which suppose he is are barren of practical application.

Much psychological effort has been devoted to prediction and control rather than understanding. Reported findings are expressed in terms of their significance, which refers to a statistical association, and does not necessarily imply any causal connection, or the direction of such connection, although unwarranted causal links are often imputed to the data from experiments. General answers are required, and individuals whose behaviour departs from the rule are a nuisance or an irrelevance, but not a stimulant to greater understanding. Thus, even when a finding becomes generally accepted, predictions may be made from it, and control over behaviour may be exerted by using it, but little attempt is made to understand it more deeply, or to relate it to man as an innovative initiator of events rather than to man as a receiver and processor of information.

Mechanistic modelling of behaviour is falling out of favour in some circles, partly because such models often have the wrong logical structure and partly because simple temporal and spatial transformations are inadequate to account for some known phenomena such as the persistence of a recognisable visual pattern through changes of size and orientation. Some phenomena, such as imagery, are essentially subjective, not wholly explicable by behavioural deduction or theoretical analysis (Sheehan[252]; Downs and Stea[290]).

Although the utility of current psychological theorising for solving or providing enlightenment of cartographic problems therefore seems severely limited, nevertheless a brief review of some theories of potential relevance may not be amiss. Cognitive mapping, originally an aspect of learning theory (Tolman[85]), has been broadened to embrace perception and decision-making (Kaplan[510]) and adaptation (Downs and Stea[511]), though the concept of a cognitive map is sometimes a linguistic convenience rather than one which can provide guidelines for compiling conventional graphic maps, though this transition is possible (McCleary[813]; McCleary and Westbrook[814]). Cognitive maps may be related to concepts of geographical orientation and navigation (Oatley[276]), and to non-visual sense modalities (Griffin[88]). Theoretical

200

explanations are commonly sought for empirical findings on cognitive mapping (Hart and Moore[297, 298]). Much of the literature on environmental perception has been reviewed by Kameron[845].

Of all the theoretical formulations used in psychology, Information Theory has had probably the widest application in cartography so far. It has been used to derive theories of cartographic communication (Board[461]; Kolacny[463]; Muehrcke[471]; Ratajski[467]), to provide a means of measuring the information content or capacity of maps (Srnka[476]; Sukhov[475]; Balasubramanyan[254]; Frolov and Maling[846]; Molineaux[477]) and to measure the information communicated by map symbols (Taylor[111, 100]). Alternative theoretical models exist, such as those based on Venn diagrams (Morrison[473, 474]; Robinson and Petchenik[459]). These are claimed to be more appropriate to cartography, but their interpretation relies much on the use of terminology from Information Theory, e.g. information, information transfer, redundancy, noise. Information theory has generally made only a limited contribution to understanding the process of map perception for the reasons expressed by Green and Courtis[847]. In order to apply Information Theory to analytical procedures there must be an agreed alphabet of signs with known objective probabilities of occurrence, perceived in a known linear sequence. One can analyse symbols viewed in isolation (Taylor[111, 100]) or one can impose a linear sequence on the perception of the map, but both completely distort the normal situation and therefore have limited predictive validity. Analysis of the information content made by superimposing grids and counting filled cells (e.g. Sukhov[475]; Taylor and Hopkin[151]) may provide an index of information density but this totally disregards positional information and offers no solution to the problem of equating the information content of one symbol as opposed to another (Robinson and Petchenik[459]).

Pictures do not lend themselves to theorising as well as patterns do, and therefore have been studied less by psychologists, although it could be contended that they are of greater practical interest. Gibson[848] attempted to develop a theory of pictorial perception, and some studies have emphasised the importance of perceiving edges and surfaces in seeing pictures (Hochberg[841]). Gibson[81] came to believe that the layout of surfaces relative to the observer and to one another constitutes what is perceived; for terrain, the amount of optical texture corresponds to the amount of perceived surface; perception relies on the persistence of visual discontinuities through time, and it implies movement by the perceiver within his perceived environment. The implications of these conclusions for map design merit detailed study. His ecological approach to perception has implications for the contending inside-out or outside-in view of the environment (Stea and Downs[92]; Kelly et al.[849]).

A promising application of psychological theory to maps is in the basic psychological laws of discrimination (Stevens[176]), and their posited extension into other realms (Stevens[850]). The question of the validity of these laws has become enmeshed in a theoretical dispute on facts and their interpretation, where it matters little in practical terms whether the contending theories are right or wrong (Wagenaar[177]). The theories have been a hindrance rather than a practical help, since either can be considered as a practical guide, provided the effects of context are acknowledged (Ross and DiLouo[540]). A better guide is the work of Williams[529, 178, 530], and the practical studies of Wright[181], Crawford[183], and Lund[785]. Perceptual theory has been used as a basis for designing practical symbols (Easterby[231]) but is not regularly applied in this way.

Psychological theories have been greatly concerned with search and detection. From the point of view of map design, most of the studies on which various theories are based relied on visual material so much simpler than maps that the validity of the theories must be dubious in map contexts. Attempts to quantify and specify stimulus dimensions do not manipulate the same variables as those in maps and can lead to inconsistent results (Brown and Michels[851]). Basic axioms of theories of discrimination learning (e.g. Trabasso and Bower[852]) have proved to be too simple to account adequately for observed discrimination behaviour without considering stimulus interactions (Spiker[853]). Searching for positive (present) targets or negative (absent) targets gave results which did not fit theoretical predictions (Brown and Chick[854]). When tested, the meaningfulness of symbols did not prove to be related, as expected, to their visual complexity (Farley[855]), but the relative meaningfulness of symbols may lead to differential search times according to the meaningfulness of the symbol that is sought (Organi[856]). Searching is also a function of psychophysical variables such as contrast (Bergstrom and Franzen[857]), and search time is influenced by information density, coding and the presence of irrelevant information (Landis et al.[193]; Krueger[858]). Sometimes redundant information may facilitate processing, perhaps by parallel processing of different coding dimensions (Biederman and Checkosky[545]). Symbol recognition is influenced by the size of the symbol set to which the required symbol belongs (Royer[859]), by the extent and nature of any symbol degradation (Sternberg[544]), and by the required task, such as deciding whether symbols are the same or different (Nickerson[536]). Some theories of search include the effects of search strategies (Howard and Bloomfield[860]).

A further theoretical concept concerns the relatedness or independence of symbols. Perceptual independence may relate either to stimuli which are perceived as independent of each other (Gardner and Morton[861]), or to stimuli which have been processed independently in terms of their information content (Leeuwenberg[613]). Independence may be influenced by the expected interference between sequences of retinal events, because of the relatively slow receptor response to rapidly changing inputs, and the mechanism required to achieve perceptual clarity (Dodwell[625]).

As stated at the beginning of this section, it would be expected that numerous other kinds of psychological theory would be pertinent to map design, but they in fact are not, mainly for the general reasons indicated. It is therefore potentially misleading to select further theories and examine them for their potential relevance to aviation maps, since

the choice of theories would be in some respects arbitrary, and those which may prove useful have been considered where they are likely to be most pertinent, for example in relation to maps as a language.

15f FINDINGS FROM OTHER DISCIPLINES

The theme of this volume, and indeed its title, is multidisciplinary. In the future, most acceptable solutions to problems of aviation cartography will probably also be multidisciplinary. Each specialist has trouble enough in keeping his own theoretical knowledge and practical skills up-to-date, without trying to achieve this for the disciplines of others; yet each must understand other disciplines well enough to appreciate their problems and their scope, and to relate successfully to them. The human factors specialist without adequate cartographic support, and the cartographer without human factors support are both handicapped thereby, compared with those who can call on interdisciplinary effort. It is rare nowadays for any one person to know everything that is relevant to the solution of a problem. An interdisciplinary approach does not entail a surrender of responsibilities, or a usurping of others' functions, but an acknowledgement that each discipline represented has a contribution to make in its own right, because of its specialised knowledge.

As the ramifications of a problem become explicit, the range of relevant disciplines is extended by additions and sub-divisions. Starting from human factors and cartography, the value of contributions by aircrew map users is evidence, and also the role of planners of future aviation systems. System requirements point towards a useful role for system analysts and for operational research specialists. Developments in display technology and in map production technology, indicate the relevance of engineering science; electronic, mechanical, chemical and aeronautical, and various subdivisions thereof. Further developments introduce computers, with hardware, software, mathematical and physical specialists. Human factors contributions may become multidisciplinary, including not only psychology and physiology, but extending to specialists in lighting, in modelling, in design, in typography, in languages etc. Cartographic contributions are expanded, to include various kinds of geographer, and those with specialised knowledge of geology, geometry, topology etc. A useful contribution can also come from those concerned with scientific methods, explanations, and logic.

While it is obviously quite impractical, and unnecessary, to call on so many specialists every time an aviation map is designed, there is an implication which is often overlooked: sources of relevant information are very widespread and dispersed. Data pertinent to aviation maps may be found in the publications and professional journals of a large number of disciplines. The role of other specialists may be to understand mapping problems sufficiently to recognise and draw attention to this information, which otherwise would be lost. Potentially relevant journal articles and sources can be numbered by the thousand. Key word indices are of limited value, since many disciplines do not share the same key words. The references in this volume both illustrate the diversity of relevant sources, and demonstate the impossibility of tracing them without specialised help and interpretation. The present authors therefore have settled for brief descriptions of potential sources of useful information, since a detailed evaluation of each specific source is beyond both their resources and their competence.

If a human factors problem related to aviation cartography is proving difficult to solve, a wider search for relevant information may be fruitful. It should, however, be accompanied by an informed specialised interpretation of the information, since a rationale for demonstrating its relevance to a particular problem in aviation mapping is necessary, given that findings do not usually remain valid in different contexts. It is also necessary to acknowledge that some problems may have no solution, and the inability to devise or discover a solution to a human factors problem should not be treated as an admission of failure if all reasonable procedures and searches for a solution have been exhausted, but should be accepted as pointing towards the ultimate conclusion that no satisfactory solution may exist.

Aviation

One definable source of pertinent information lies in other branches of aviation, not normally concerned directly with maps. These include the following:

(1) With aviation medicine, many of the issues which affect aviation maps are discussed in relation to other issues. Examples include colour vision requirements, endurance and fatigue, the effects of the physical airborne environments on performance, and items of protective clothing and equipment which affect map handling.

(2) Reports of accidents or incidents during flight, and subsequent discussions in the flight safety literature, may indicate failure in map design, reading or interpretation as contributory causes of navigational errors, and alert the cartographer or the human factors specialist to deficiencies in map specification or production, in map training and understanding. This presupposes the selective dissemination of the appropriate flight safety reports.

(3) During flight training, conversion courses, and other occasions when aircrew are under instruction or being assessed, numerous events may reveal inadequacies in map usage, or incompetence on the part of map users. The cause may lie in the map itself, in the way it is explained to users, or in the individual user. The body of evidence obtained from numerous instructors' reports on navigation exercise may assist in assigning the cause and in proposing the remedy.

(4) The general aircrew literature, and numerous aviation journals, provide guidance in articles and correspondence columns of attitudes towards maps, and towards cartographic and technological changes which affect map usage. They may also reveal whether general attitudes towards the job or its conditions extend to maps, and whether attitudes, favourable or unfavourable, apply to all maps or only to a particular series or a particular role. It may be pointless to interpret adverse comment about a map as requiring urgent revision of the map, if the adverse comment is not specific to maps at all but calls for much more general solutions.

(5) The wealth of evidence about the surface of the earth now being gathered from satellites (Estes and Senger[862]; Harris[863]) may provide a new visual frame of reference against which maps are judged. Users may come to expect a map base which looks more pictorial or photographic, and presuppose that a highly symbolic map, being further removed from their notion of the real world, must therefore be less efficient. They would not normally be aware of evidence that such a supposition would probably be wrong.

Cartography

A further source of relevant evidence may be new approaches to cartographic problems or developments in other disciplines which may affect cartography. These include the following:

(1) The approach which Bartz[509] applied to typographic legibility in relation to maps could be extended to other topics, such as colour coding, linear perception, symbology, or information density. Her critical appraisal of the literature on typographic legibility led to the conclusion that most of it was probably not applicable to maps because reading a map was very different from reading a text. Similar conclusions could probably be drawn for other topics.

(2) A psychological appraisal could be made of cartographic design standards and of the scientific validity of the processes by which they are reached. It may be profitable to gauge the extent to which certain aims of design standards, such as the visually layered separation of information within the map (Adams[490]), are in principle attainable.

(3) Modern computer methods could in theory be applied to cartographic data to derive or interpolate operationally significant information not normally available for mapping. One example would be the derivation of ridge lines, and their depiction. Such interpolated data may require different conventions for its depiction, either to denote that it is interpolated by computation, or to give visual guidance on its quality and on the reliance to be placed on it.

(4) The urge to seek explanations for maps, their functions and their design principles, is an aspect of a search for explanatory concepts among the geographical sciences, epitomised by Harvey's text[465]. Ideas on the role of maps may be developed by speculating about them (Robinson and Petchenik[459]), or by viewing them in relation to recent geographical literature as a whole (Harris[863]).

(5) The scientific method may employ a variety of languages, often with a mathematical basis. The artificial languages of science, as distinct from natural languages, employ many abstract concepts and rigorously control their usage. Each sign in the language has a fixed function which should be unambiguous, not subject to whim of interpretation. Such signs are used to build systems of relationships, which need not have empirical equivalents, but which are intended to be universally valid. Artificial languages are therefore unambiguous in themselves, but may become ambiguous if subjected to unwarranted or extended interpretation. A map is the geographical equivalent of such a language, and therefore should possess its main characteristics, and be amenable to study as an artificial language (Harvey[465]).

Human Factors

Relevant evidence may also be gleaned from human factors problems not normally related to maps, and from technological developments which generate problems analogous to those of human factors. These include the following:

(1) Algorithms for the generation, recognition, analysis and classification of patterns by computer, and the conversion of patterns from analogue to digital form, suggest methods for describing patterns and forms in quantitative terms, and for specifying quantitatively the similarities and differences between them. How far the consequent magnitudes of change accord with subjective impressions would have to be established if maps were subjected to these procedures, and it would be expected, from the conflicting evidence on Fechner's law, that the relationship between objective and subjective changes could not simply be expressed as a linear, exponential or geometric transformation. Nevertheless, starting from computer specifications of patterns, it might be possible to derive rules for quantitative relationships which would predict discriminability, search performance, or recognition probability sufficiently well for operational performance to be deduced, or for judgements to be made on the pattern and form specifications which would be necessary for a designated level of operational efficiency in task performance to be achieved.

(2) Patterns derived from other sensors also have to be analysed and interpreted. The advent of many new sensors, in aviation and elsewhere, means that principles for their interpretation have to be defined and taught. Some may employ principles which are shared with maps, or with collateral material used in conjunction with maps. Some may illustrate failings or limitations in pattern perception and interpretation, which may be general and apply to maps also.

(3) Occasionally, maps are cited as analogous of other processes, or as having affinities with them. An example is Bartlett's[87] use of sectional map reading as an analogy of scientific experimentation. In his consideration of adventurous thinking, he illustrates common decision making processes in scientific experiments and map reading, and compares some conditions, where all the information available is pertinent to the decision, with others, where the available information may not be fully adequate for the decision. Such studies, though not intended as a contribution towards the study of maps, may nevertheless be a source of useful insights and hypotheses in map design, usage and evaluation.

(4) The human factors literature, in dealing with the aetiology of errors, seeks general practical solutions to problems, but must also be concerned with the conditions which may lead to an increase in errors in the individual. Some individuals may simply make more errors than others, in map reading as in other tasks, due to differences in ability, in interest, in personality, in knowledge, in experience, in age, or in other attributes. But the propensity of an individual to make errors, or to show other performance decrements such as delays, omissions or a lack of accuracy, precision or consistency, is broadly associated with other variables which can usually be related in some way to time, and expressed accordingly. More specifically, an individual's performance can be expected to depend on how long he continues to do the task without a rest, on the nature, length and distribution of rest pauses, on the scheduling of work-rest cycles, on their interrelationships with circadian rhythms, and perhaps even on biorhythms of longer duration. Optimum work scheduling depends also on the nature of the task and on how demanding it is, but normally performance of map reading tasks would be expected to relate to such factors, in the individual and generally, and to have some potential for enhancement by optimum times scheduling of work periods.

(5) The processes of reasoning, problem solving, and designing in map making and map reading can be studied as psychological processes. The decision making processes in arriving at a map specification are themselves amenable to study, with a view to assessing their logicality, objectivity and efficiency. The factors which apply to other kinds of decision making would be expected to apply also to decision making in mapping, so that decision theories may not only be applicable to studies of map content but may also be valid for certain stages in map specification, production and evaluation. The psychologist's methods for measuring decision making, problem solving, and other functions may be applied to the many cartographic activities in which these functions are represented, and may enable an optimum to be established so that the efficiency of various activities can be measured, and sources of inefficiency identified.

CHAPTER 16

THE APPLICATION OF HUMAN FACTORS PROCEDURES TO AVIATION MAPS

16a STAGES OF HUMAN FACTORS CONTRIBUTIONS

In general, the most significant applications of human factors knowledge occur early in the evolution and design of a product, before major constraints have curtailed the decisions that can be taken. This is as true of maps as of other products. However, the timescale for producing maps is long, and changes to existing maps are more difficult to introduce than changes to most other items. In many other contexts it is possible to change an inadequate display, control, communication link or other component and leave the remainder of the system substantially intact, whereas most changes to a map require the whole map to be remade, and a large part of the production cycle to be followed again. If new evidence becomes available at a late stage in the production cycle, it may therefore be unusable until the sheet is due for revision when the information may already be out of date. It also follows that the evidence must be correct, since it may be impossible to retrieve the consequences of faulty evidence once it has been incorporated into the production process, particularly when the printing stage has been reached. Careful planning and co-ordination of amendments with revision cycles are necessary to maintain an up-to-date accurate product and to prevent wastage due to over-production.

The most influential human factors recommendations must necessarily be expressed in general terms since they are made at a stage in the design of the map when none of its details have been settled and there is not yet anything specific to make recommendations about. Although much of the practical knowledge gleaned from theoretical and applied experimental studies is quite specific, these more general decisions will determine whether it could ever become relevant at all.

An aviation map is intended for a purpose, or, more usually, for many purposes. Its specification must, if possible, meet operational requirements. Effective human factors advice may be tendered during the formulation and development of operational requirements. It is pointless to write an operational requirement which cannot be met because of some fundamental human limitation, and the cartographic implications of any proposals should be explored to ensure that the requirement does not entail any tasks or procedures which are beyond human capabilities or which require cartographic support which is unattainable. At this stage also, research needs can be identified early enough to complete experimentation in time for its findings to be implemented in the final product. Sometimes it will not be possible to state whether a specific task could be done or a satisfactory solution to a given problem could be found. Currently, for example, in relation to the problem of reading maps through image intensification passive night vision goggles, the levels of performance that could be achieved with optimised mapping and training cannot yet be fully stated, because many intervening problems have yet to be solved. Similarly, cartographic solutions to the problem of interpreting combined radar and map displays can be devised and proved, but without any great confidence that the best solution has so far been found. During the formulation of operational requirements which need cartographic support, the human factors consequences of the proposals have to be identified and made as explicit as possible. General knowledge about human capabilities and limitations and about principles of information display needs to be combined with more specific relevant findings to permit conclusions and deductions about task feasibility and research requirements.

After this stage has been reached, and the objectives of the operational requirements have been accepted as feasible, human factors advice becomes more concerned with how they should be met. The emphasis changes from stating what knowledge could be applied to actually applying what is known. At this stage, the question may still arise of whether a map is the most appropriate means of fulfilling a requirement, and the map should be viewed as one of a series of alternatives. For example, it may be envisaged that the operational requirement must include some form of continuously generated display of the terrain over which the aircraft is flying, e.g. a TV monitor picture, a side-scan radar or an infra-red linescan. This in turn may require some form of collateral material and preflight briefing information to facilitate in-flight interpretation. But it may not be clear whether, for greatest operational efficiency, this collateral material should be cartographic or photographic in origin, and, if cartographic, what information should be selected, how it should be portrayed, or whether it should be in paper or projected form. The implication however is that the problem can be solved. The aim is to find the best solution or, at least, an operationally acceptable one.

Initially, the main emphasis is on human abilities and limitations, and on methods for utilising potential and circumventing limitations. At each stage, it is necessary to decide whether a particular task is feasible, before progressing to detailed considerations of how it should be done. It must be established that a man could perform each task in principle, before there is any point in devoting effort to deciding his information requirements. It is futile to provide information without ascertaining that it is in a form which the man could use. If the interpretation or understanding of

the portrayed information requires specialised training or knowledge on the part of the user, he must be able to acquire the necessary skill. Even though a map specification and the resulting product are intelligible to a cartographer, it does not follow that aircrew will appreciate all the coding distinctions and meanings that have been judged to be necessary for the task. Therefore, to some extent, one human factors contribution is to bring the point of view of the user to the design stages of the map.

A further contribution is in testing the soundness of proposed solutions to cartographic problems, using empirical methods rather than relying solely on expert opinion. This is not to decry the cartographer's opinions, often well-founded on a basis of detailed knowledge and long experience, but it is to recognise that such opinions may become entrenched through time and tradition, and that technological advances may reduce their validity. If the opinions rest on a basis of sound fact, they can only be strengthened and vindicated when they have been certified empirically. If they do not have a basis of factual evidence, then their value for the user, and his efficiency when using them, must be impaired and it becomes essential to discover how they are justified. A forthrightly stated opinion may be backed by no evidence. This can be a particular difficulty when attempts are made to reach international agreements on map specifications which require hitherto incompatible cartographic traditions to be melded, and subsumed under a common standard. He who voices the most insistent opinions may be listened to most, but this is not a satisfactory way to produce a good map.

Differences of opinion among human factors specialists on how they can help to solve cartographic problems are not large, and agreement can normally be reached on whether a given finding about maps should be treated as valid. Because the human factors specialist is not directly involved with the aviation map as the cartographer and the user are, his advice about its design can more readily be accepted as impartial, since his role can be seen to deal with establishing facts and applying them objectively, rather than defending an entrenched conviction which may be impossible to sustain. The human factors specialist can therefore contribute a great deal by remaining scrupulously impartial, and by being seen to be so.

Human factors evidence on the user's requirements often comes in the form of a task analysis. This includes deductions on the functions which the map must fulfil, the information it must contain to fulfil those functions, and the formats needed to ensure intelligibility. The task analysis must consider not only the tasks which are done with existing maps, but further tasks which could be done if appropriate cartographic information could be provided in useable form, or which are implied by new operational needs, new display technology, or new cartographic developments. This process can be quite straightforward if a map is intended for one task only or for a limited series of functions. It becomes more complex as further envisaged functions are added, requiring ever more information to be shown on the map. Each task will require a different selection of relevant information from the total information portrayed, much of which will be irrelevant for some tasks, though essential for others. Consequently, not only does a multiplicity of tasks lead to a high density of information on the map, but the differing information requirements of differing tasks mean that simple principles for conveying the relative importance of information for the user cannot be followed for every task. Either some information vital for certain tasks will lack adequate visual prominence, or a loss of visual balance will be associated with excessive visual competitiveness of various information categories. The task analysis will serve to demonstrate any universal information priorities, common to all tasks, and it will reveal when the required functions have become so numerous that the resulting cartographic problems of density and portrayal no longer have an acceptable solution.

A task analysis may be conducted at various stages during the planning and production stages of a map. During early stages, though it cannot be detailed, it may provide guidance on the kinds of task which could be done, and give an early warning of functions unlikely to be fulfilled. Later, during the production stages, its purpose has changed since design modifications are no longer possible, but specific detailed recommendations on functions for which the information on the map will prove to be inadequate can then be made. At intermediate stages, the conclusions from the task analysis become progressively less general, more specific and more detailed, as the information which will appear on the map becomes more closely defined in content and format. In principle, the task analysis can be used to show what information needs to appear in a useable form on the map if functions are to be fulfilled, and can also be used to list the functions for which an existing map will or will not prove to be adequate. The reason why this is possible only in principle is that the task analysis must to some extent assume that the problems of finding an adequate means of information can be satisfactorily overcome, and that the user will be able and willing to acquire the necessary knowledge, training and skills to make effective use of the information. The task analysis can go some way towards identifying the skills and abilities which the user should have, but it will not normally provide sufficient information for a training schedule to be devised on the basis of the task analysis alone.

It is necessary to establish what information is needed before finalising the methods for its portrayal. Occasionally, difficulties of portrayal may pose insuperable display problems, particularly visual clutter, which may warrant some reappraisal of the tasks to be performed and the information needed, but a main criterion of successful portrayal is that it meets operational needs, and if possible it should do so. One human factors contribution is to relate what is known about principles of visual information display and interpretation to cartographic production methods, conventions, and traditions. Knowledge of the meaningfulness and discriminability of various coding dimensions can guide the categorising and subcategorising of cartographic data. Principles of perceptual organisation can indicate what will be perceived as a visual entity, as visually related, as figure or as ground. Coding dimensions can be assessed for their suitability for fostering desirable visual similarities and differences. Errors in the transmission and interpretation of

visual data can be examined in relation to map information categories. The impressions of quality and accuracy of information, which symbols may deliberately or inadvertently convey, can be set down, and the method of coding can be adjusted to avoid any potentially misleading consequences. Principles of visual interactions and interference can be stated, and their cartographic implications explored, and even compensated for. The extent to which meaning is conveyed by coding, and the extent to which it is attributed to a coding, perhaps wrongly, by the viewer, can be defined to minimise such errors of interpretation. How much the user needs to know and remember in order to interpret the map correctly can be specified, and to some extent the map may be designed to aid his memory, if the resultant training and memory loads are judged to be excessive.

The visual portrayal of information may be adjusted to facilitate the performance of non-visual tasks revealed by the operational requirements and task analysis. Tasks with a major memory component are an example where symbols that are easily recalled may be preferred (e.g. pictorial symbols). If it is envisaged that the user must send or receive cartographic information verbally, then verbal representations may be preferred (e.g. place names). A further aim may be to help the user to develop accuracy and speed in map usage. If visual tasks require matching the map with other displays, the map design may be modified to facilitate matching. Sometimes existing knowledge will prove inadequate for practical recommendations, either because it does not exist or because of uncertainty on how far apparently pertinent findings can be generalised.

A further stage at which a human factors contribution can be made is in the collection of relevant evidence to enable a decision to be made on the most appropriate method of cartographic representation. Human factors brings a knowledge of valid methodology for measuring and assessing the performance of individuals, and their capabilities and limitations. It also brings a knowledge of the nature, extent and causes of individual differences. Thus, not only the kinds of measures needed to provide a correct answer can be stated, but also the commitment in experimental resources which would be needed to obtain experimental findings at an adequate level of confidence. The experimental material required to obtain an answer within the limitations of cartographic technology can be specified. The relevance of alternative kinds of data – performance, subjective, physiological, etc. – can be assessed. Alternative techniques – experimentation, modelling, psychological tests, questionnaires, etc. – can be compared and evaluated. Theoretical frameworks – decision theory, information theory, signal detection theory, gestalt theory – can be examined in terms of their descriptive and explanatory value. Specifically psychological techniques – projective testing, semantic differentials, repertory grids, operant conditioning – can be appraised.

A final human factors contribution can be made towards the assessment of the map in use. Its usage may be evaluated in relation to its objectives, be treated as a factual descriptive process, or be examined in relation to proposed extensions of use beyond the original objectives. Usage also depends on the physical environment, and on the skills, training and knowledge of the user. Usage may be examined in relation to a particular development (moving map display), a particular constraint (severe vibration), a particular type of mission (low speed low level at night), or an envisaged map revision. Data on how the map is used can assist the planning and evolution of new map series for future operational roles requiring maps, where the questions of whether cartographic information is necessary, and if so what form it should take, start another cycle of human factors contributions to the development and evaluation of aviation maps.

16b SEQUENCE OF CONTRIBUTIONS

The application of human factors principles to maps typically requires a sequence of specialist contributions to each map. In practice, the human factors specialist can expect to be working concurrently on several maps. Therefore at any one time he deals with several problems at various stages in the sequence of his contributions, as each stage is reached with each map. However, the sequence of human factors contributions is best understood by considering a single map, and describing his contributions to it in the order in which they are made.

Identifying the Objectives

Any map, whether in paper or other form, has a series of objectives to fulfil. The first contribution that human factors can make is therefore to the statement of objectives. These are derived from operational requirements, and interpreted in relation to operational experience with existing maps, particularly those with comparable objectives. The feasibility of any proposal is judged according to known capabilities and limitations of users. These may be expressed by fundamental concepts, such as perception, attention, learning, memory, skill, and information processing, but it is also necessary to estimate and take account of the probable enhancement of abilities following appropriate training to gain relevant knowledge and skill.

Known attributes of the user may be related at this early stage not only to the map itself, in terms of its design and content, but also to the circumstances of its use as stated in the objectives or implied by them. For example, if the map must be projected, interpreted in relation to briefing material, used with a collateral display, viewed under red ambient light or through goggles, or employed in a vibrating environment, such factors may profoundly affect the feasibility of producing a map to meet the required objectives. They must therefore be thoroughly appraised while the objectives are still fluid. If the available coding conventions are severely curtailed, the map may retain little practical value. A monochrome map, for example, cannot have comparable levels of detail to one with full

colour coding, without incurring severe penalties in the time required to interpret it, in the unlikely event that the resultant problems of portrayal can be circumvented.

At the earliest stages, therefore, human factors may advise that the objectives envisaged for a map are unattainable. Obviously, there is no point in devoting time and effort to evolving and writing a specification for a map, if the viability of the whole project is suspect. Its viability is established by using general existing knowledge on human abilities in association with evidence derived from cartographic design and practice and from practical guidelines on display design, coding, communication, information processing, and display interpretation. This existing knowledge includes not only what the users can do, but also what they could ultimately learn to do, in the light of what is known about their existing skills, training, knowledge and experience, and the magnitude of individual differences between them. At this stage, there is no map. However, this stage is emphasised here because in practice it is so often undervalued. With hindsight, if a map has failed to meet its operational requirements, it is often realised that this could have been foreseen if the opportunity to deduce the human factors implications of a proposal had been seized, and the consequent human factors problems had been identified, stated, and shown to be insuperable. Thus the first human factors contribution is to say whether a proposed usage is viable at all.

Defining the Objectives

If a proposal seems to be viable, then the next stage should be to ensure that the objectives are written in a way which takes cognizance of their human factors implications. This again sounds self-evident, but it is seldom done. In particular, it is usually possible to identify at this stage topics on which more information must be gathered, either by experimentation or other methods such as task analysis or consultation with proposed users. It may not be possible to say whether or not an objective is feasible, or, more commonly, to what extent or under what circumstances it will remain feasible, but it usually is possible to be quite specific on what the elements of uncertainty are. These should be defined as early as possible, since the time-scale for gathering the relevant information to establish feasibility may be quite long, and it is essential to do so thoroughly before too many resources have been committed. This constraint can be particularly important if any experimentation with cartographic material is envisaged as necessary to obtain the data, since the design and preparation of special cartographic material is itself a protracted process. There may, however, be no alternative means of settling the issue validly.

A statement of proposed objectives should include the details of the envisaged operational conditions under which the map will be used and the functions it will serve, to enable deductions to be made about the human factors implications and the consequences for map content and design. This analysis should also be made as early as possible, before or soon after the statement of objectives. It is necessary to know what a map is for before it is possible to state what information should appear on it. It is necessary to know the complete range of envisaged uses for the map, before the information needed to fulfil every role can be adduced. And it is necessary to adduce all this information before judging whether the implied level of cartographic detail is excessive or not. If it appears to be, then several alternative actions may be taken, and these can be stated. They include using a larger scale of map to enable all the required detail to be accommodated, though the map production implications of such a choice are formidable. They also include a reappraisal of the objectives, with a view to revising them until the resultant cartographic information requirements are no longer excessive. They include a reallocation and regrouping of objectives, so that they are divided between different series and are all fulfilled, but not all by the same map. A variant of this is to introduce a series of related maps with common base data but with a choice of overprinted material specifically for a single operational role or a group of roles. The feasibility of these alternatives can be established by the same basic methods – examining the tasks, deducing the necessary information and consequent problems of portrayal, and checking the feasibility of each task and each possible coding against known human abilities and limitations. More specifically these are usually concerned with search, identification, route planning, navigation and similar tasks, but the value of the map for liaison or for reorientation after becoming lost may also figure prominently among operational objectives.

The above earliest human factors contributions are the most important, but made least often. A mistake at these early stages cannot normally be redeemed later. A failure to realise when an objective is unattainable, that a task cannot be done in the time available, or that a map will become unreadable under certain environmental conditions may mean that the user is provided with a map unfitted for its purpose, but it is then too late to do anything about it, except start again and make another map.

Designing the Tasks

A human factors contribution can next be made towards gathering information relating to the user's envisaged tasks, towards establishing their feasibility and towards interpreting existing information in the light of new tasks and objectives. This involves a thorough knowledge of sources of pertinent information, of the kinds of information that are of potential relevance, and of methods for gathering and interpreting valid additional evidence. This implies a broad knowledge and an eclectic approach on the part of the human factors specialist. Otherwise, some pertinent evidence will be overlooked. It also implies informed judgements on the probable applicability and generality of findings, and on the value of theories, constructs and models.

Experimentation on an empirical basis may sometimes be necessary. Alternatively, it may be fruitful to test the explanatory or predictive value of a particular set of theoretical constructs. The potential relevance of many general

psychological concepts and methods should be assessed. Usually they are claimed to be of general relevance and applicability; often they fail to fulfil their promise when applied, but sometimes they may account satisfactorily for evidence which would otherwise by puzzling. Information theory and its derivatives, and the principles of information display, should have relevant concepts to offer. In so far as cartography is a language, it may be possible to adapt concepts such as semantic differentials and repertory grid techniques to study aspects of maps. Theories of stochastic processes, decision theories, and signal detection theory, may be pertinent for tasks with probabilistic aspects, such as searching a map. Mathematical approaches, such as control theory and fast-time simulation, may have relevance. Principles of perceptual organisation and structuring should not be violated in map design. The design should not assign meanings which are difficult to reconcile with the intrinsic meaningfulness of pictorial attributes of the symbology. Learning principles, the processes of acquiring skill, and practical aids to memory, should not be ignored, but incorporated and utilised where possible in specifications for map content and design. The skills and abilities of those who use maps and those who make them can be treated both in general terms and in terms of differences between individuals. On all the above topics, and on allied ones, a knowledge of the basic concepts, their nature and their applications, and of where to find out more about them, is essential if a full human factors contribution is to be made. Competence in experimental procedures is also essential. Some knowledge of aesthetic factors and of attributes may also be helpful in relation to map design and map acceptability.

Designing the Map

Human factors contributes at the stage of analysing the tasks and of deducing what information should appear on the map. These stages, though they constitute a lot of work, are quite straightforward; they do not call for innovative techniques, but for the thorough and painstaking application of techniques already established. The result is a list of functions to be performed, and a list of the essential cartographic information, initially classified by function, but subsequently compiled in categories of cartographic information. Given this, the human factors contribution towards the design of the map, its format and coding can be made. Human factors is usually associated with map design but the main decisions with human factors implications have been taken long before questions about methods of representation and symbolisation arise.

In dealing with design issues, the amount of information to be portrayed has to be considered first. The severity of the human factors problems to be resolved depends to a considerable extent on the density of information to be included on the map. Human factors can advise on the implications of various cartographic practices for the user. Map generalisation, with its smoothing effects, may alter the general impression of the nature of the terrain which is conveyed to the user. Whereas hill shading may give a false impression of the coarseness of terrain, contours may give an impression of smoothness, continuity, and gradualness of progressive transitions which is belied by the real landscape which the map purports to represent. Human factors can also advise on the appropriateness of methods for conveying the accuracy and precision of the data presented. In particular, methods of portrayal should seek to avoid spurious implications of precision.

Analyses of map tasks in terms of criteria such as their frequency and operational importance permit deductions to be made on the emphasis that should be given to different categories of cartographic information in the overall design. Sometimes this leads to conflicts which have to be reconciled with traditional cartographic practices. For examples, on topographical maps relief is traditionally depicted as the background, with man-made features as the foreground. But for tasks where the terrain has greater importance, such as nap-of-the-earth flight or radar map matching, it may be necessary to give more prominence to relief portrayal, at the expense of other features. Novel solutions may be proposed, such as the prominent depiction of ridge lines, but these must be compatible with survey methods and the requirements for accuracy. Nevertheless a human factors contribution is to propose and test possible solutions to such practical difficulties, always within the constraints of effective portrayal.

Human factors knowledge can be applied to determine the discriminability of symbols, but it is necessary to do so with caution, because findings from non-cartographic contexts do not generally transfer, though the principles on which they are based are of general applicability. For example, recommendations on the legibility of typefaces do not transfer in detail, although more general findings about the relative merits of alphanumeric, geometric and pictorial coding conventions remain relevant. Data on colour discimination, for instance, remain valid in all contexts although their detailed nature is modified somewhat by the visual complexity of cartographic backgrounds and the multiplicity of colour codings employed.

Experimentation to discover the application of general visual coding recommendations to maps is also straightforward, although it may require specially prepared materials, produced within the contraints imposed by map production technology. The number of visual dimensions can be specified, and the number of levels or intervals within each dimension. Also the discriminability and logical interrelatedness of subcategories of symbology is amenable to testing. Discriminability can be tested also for particular conditions, such as projected moving map displays or low or coloured lighting levels. Hypotheses needing to be verified in a map context can usually be found in the general displays literature. It is often simpler and more effective to check the validity of existing general display recommendations for maps than to embark on a major experimental programme as if no other evidence about displays existed. As a general principle, existing findings should be treated as hypotheses, requiring verification for maps.

The formulation of codings to be tested draws on human factors data, on traditions of cartographic coding and meaning, and on logical principles of vision and semiotics to convey the required variety of meanings, show their interrelatedness, and ensure that visual categories and subcategories correspond sensibly with required nuances of meaning. Alternative coding dimensions – size, shape, colour and so on – may be considered, and also alternative visual forms for the same information – symbolic, pictorial, alphanumeric, and so on. Human factors guidance is used to ensure that only serious and sensible alternatives reach the stage of experimentation. Other less satisfactory alternatives with a serious flaw have to be identified and discarded, with the reasons for doing so clearly stated. At this stage in the sequence of contributions, experimentation is orthodox, employing conventional designs and statistical treatments, with a careful selection and definition of the conditions studied within each variable. Less orthodox is the interpretation of the experimental findings: although the design of the experiment may be a standard one, any change in a map which affects the portrayal of one cartographic information category has interacting visual effects with many other categories, affecting contrast, discrimination, balance, visual similarities and differences. Consequently the effects of a simple visual change can become very complex, and a human factors contribution is to define the full range of effects resulting from a single simple change on one category.

Evaluating the Product

The last human factors contribution is to the map in operational use. At this point, very little can be done to change it, although it may still be necessary to reconcile environmental conditions, such as cockpit lighting, with cartographic legibility. The extent to which the map fulfils its objectives can be assessed in various ways. The users may be asked for their opinion of it, and human factors advice will ensure that a properly designed questionnaire is used to gather valid and reliable opinions. The gibe that asking twelve pilots for their opinion produces twelve different answers is usually a reflection on the professional competence of the questioner. A competently designed questionnaire should not contain any items which can be answered in so many ways as this would give rise to difficulties in scoring the replies and analysing them satisfactorily. Respondents may be invited to amplify their answers, and may then do so in different ways, but the questionnaire itself should be designed to give a limited number of firm clear answers to each question, so that the interpretation does not depend much on the subjective impressions of the questioner.

In addition to, or instead of, subjective data, measures of performance of various tasks using the map may be taken, as a means of assessing it. The whole range of tasks envisaged in the objectives should be examined by performance measures; alternatively a representative selection of tasks may give an assessment which is less thorough but sufficient to show that the map is unsatisfactory. Performance measurements may also be used to examine a single objective in detail, if the expected operational achievements are not being fulfilled. In this case, one or more highly specific tasks may be examined by detailed performance measures. In this context, though not necessarily in others, it is convenient to subsume eye movement studies under the heading of performance measures, since their intention is to reveal what information is used to perform a task.

A further approach is to check the information needed according to the task analysis, against the information portrayed on the map. This will reveal if certain essential information is not present, or if, though present, it is inadequately portrayed. When the human factors worker is making this kind of contribution, his role has almost come full circle, since he is carrying out a similar activity to that which is a precursor of a new map design, namely systematically examing the deficiencies of existing maps, in terms of their content and methods of portrayal.

16c A HUMAN FACTORS CHECKLIST FOR AN AVIATION MAP

This checklist, in the form of a list of questions, covers issues which commonly arise during the application of human factors principles to an aviation map. It is intended to aid the human factors specialist and to inform others on what his contribution should encompass.

The level of detail of the questions was swayed by two intentions. One was to keep their total number within reasonable bounds, without making them too diffuse or vague. The other intention was to pose general questions of potential relevance to all aviation maps. Although almost every question could be subdivided into more terse and specific items, these subdivisions would no longer be universally applicable.

Objectives

Is the map new or intended to replace an existing map?
Is the map primarily for visual or instrument navigation or for both?
Have all the operational roles of the map been defined?
Are there any further roles, not yet defined operationally, which the map may be required to fulfil in the future?
Do any of the envisaged roles imply requirements known to be incompatible?
Are the requirements of various roles so different that too many different kinds of cartographic information must be portrayed?
Will the map be self sufficient during each mission or will other maps be needed?
If other maps are needed, will they be compatible with this map?
Will the map be used in association with any other form of collateral or continuously generated material?

If so, will it be suitable for this purpose?

Will the map be used for liaison and serve as a basis for conveying cartographic information verbally?

Will the map be intended to fulfil all the requirements at various stages of a mission, e.g. briefing, planning, in-flight, de-briefing, etc?

Are the envisaged scale and projection the most suitable for efficient use considering the stated objectives?

Have the objectives been defined clearly enough for the design and content of the map to be planned?

Do the objectives delineate all the envisaged conditions of use, including the various aircraft types, the different aircraft speeds and heights, day or night flying conditions if applicable, and the methods of display within the cockpit?

Do the objectives delineate all the kinds of terrain and all the geographical regions for which the map is envisaged?

Have the requirements for accuracy and revision of the map been stated?

Is the map intended to be produced by a single cartographic agency or by several production establishments?

How have the objectives of the map been defined, and what sources of influence have been neglected in defining the objectives?

Physical and Environmental Considerations

What physical attributes of the workspace (e.g. flight planning room, cockpit, etc.) will limit map usage?

Is the map intended for use in a vibrating environment and has this been taken into account in its specification?

Has its specifiction been influenced by other relevant conditions of use such as the lighting conditions prevailing in the workspace?

Is the map adapted for easy stowage and retrieval in the workspace?

Can the map be handled in all required conditions (e.g. when wearing gloves)?

Can it be readily and correctly identified in the flight planning room and in the cockpit, so that it is not confused with other maps or job aids?

Does it have to meet any specialised viewing requirements, such as being viewed through image intensification night vision goggles?

Does it have to withstand television and photographic processing and projection in a moving map display?

Is its specification compatible with probable advances in display technology which may influence its use or form of presentation, initially or in the future?

Is it intended to be used with any superimposed material, and is it potentially compatible with such material?

What tools will be used with it for measurement, annotation, and for adding route plan and tactical information etc., and can these tools be used under the envisaged workspace conditions (e.g. vibration, wearing gloves, etc.)?

Is it required for national or international use, and what nationally or internationally agreed conventions have to be followed in its specifiction?

Is it intended to be semipermanent, or used on one occasion and then discarded?

Have several sheets of the series to be used to assemble map strips, and does the specification facilitate this process?

How do the sheets relate to each other, and do they overlap or facilitate alignment under adverse conditions?

Do the sheet lines take into account the major routes and main airfields and areas of flight?

Is the map intended for use by one person only, by different crew members sequentially or by several in consultation, and how have these requirements influenced its design?

Tasks

What range of tasks is the map intended for?

Have all the tasks equivalent operational significance, or should some weighting of their relative significance affect the map design?

Can all the required tasks be done on a single map, particularly with reference to its legend categories, its scale, its level of detail and generalisation, and the conventions followed in its portrayal?

Is the initial classification of tasks adequate to enable the human factors requirements to be specified?

Are the tasks descriptions speculative, based on deductions, or derived from direct observations of aircrew and of how maps are used?

Has there been adequate consultation between cartographers, map users, and the planners of tasks and roles?

Can all the tasks, expressed in terms of aspects of the mission such as pre-flight planning and briefing, take-off, cross-country navigation between checkpoints, reconnaissance, etc., be defined so that their psychological aspects, such as search, identification, etc., are clear?

Are the task descriptions adequate to decide what information must appear on a map used to fulfil them?

Is it necessary to conduct fuller job descriptions, task analyses, activity analyses, surveys or detailed planning in order to specify the required tasks more adequately?

Do any of the envisaged tasks and requirements seem impossible to achieve, or is any of the information which will be required impossible to convey.

In so far as the human factors problems inherent in the task requirements can be envisaged, do any of them seem to have no solution?

Are there any changes which could be made in tasks which would make the solution of map reading problems much easier?

Users

Who will use the map?

Is it necessary to select users on the basis of map reading performance or other criteria, e.g. visual acuity and colour vision?

Do the users already know enough about map usage, or will they have to be trained to carry out the tasks?

What training methods will be used, and how will their efficacy be tested?

Do the users need to have any knowledge of the cartographic constraints which have influenced the form and content of the map?

What maps are the envisaged users already familiar with, and are any proposed map design changes or innovations a potentioal source of errors or misunderstandings by the user?

What information on existing maps is ignored by the users because they cannot understand it or are unaware of it, and what steps are being taken to ensure that all the information on this map will be seen and understood?

How should the map legend be designed to aid understanding and act as a training aid for map reading?

Are other instructional guides necessary?

What steps will be taken if a significant proportion of users are unable to make adequate use of the map?

Are major differences expected between different users in the conditions under which they will use the map, or in the time available for map usage?

Have users been instructed in potential sources of error in map reading and in the quality of the information on the map, its accuracy, and the trust which should be placed in it?

Do the users know how to use various means such as grid referencing for describing map locations independently of map contents?

Do the users know how to estimate and measure distances and directions on the map and in the field?

Do the users know the correct terminology for various features and relationships conveyed on the map, and can they use this terminology correctly?

Can the users interpret the tactical significance of information shown on the map?

Have the users been instructed in the correct way to use the map for various operational tasks, and have the procedures they follow when using maps been optimised and standardised whenever appropriate?

Are there adequate means for consulting map users, for measuring their performance, and for establishing which tasks are performed to operationally required standards and which need to be improved?

Specification

Can the specification be followed and interpreted without ambiguity by all those involved in the production of the map?

Should the specification be designed for, and made available to, map users?

Is the specification too rigid, or insufficiently flexible for production interpretation?

Is all the information needed to produce the map and meet the requirement contained in its specification?

Are the chosen projection scale and sheet size optimum for all the envisaged tasks, or should some tasks be reassigned to different maps?

Are the format, projection and scale compatible with collateral or superimposed material?

Content

Are all the categories and subcategories of information selected for depiction appropriate for the tasks so that collectively they provide all the information needed for the tasks to be done?

In selecting categories and subcategories for portrayal, what solutions will be adopted if these lead to very high or very low densities of features in certain geographical regions?

How are the principles of generalisation applied, and how far has the character of a region been preserved?

What sources of error of inaccuracy have been introduced for cartographic reasons such as generalisation, and how will they affect task performance and user's interpretations?

What effects have compilation methods had on the map specification?

What information does the cartographer intend to convey on the map, and is his choice of categories and subcategories adequate in human factors terms to convey that information, assuming no deficiencies in portrayal?

Can all the envisaged contents be justified on the grounds of relevance to the task(s) and how much information is redundant or irrelevant?

Coding

What limitations on methods of coding are applicable, and have these led to any ambiguities?

Are all the codings chosen discriminable under the circumstances of their envisaged use?

Are any codings sufficiently similar in their visual appearance to be confused?

Are any codings misleading, for example by being symbolic and appearing pictorial or by looking like one thing while representing another?

Do the codings logically relate to the categories and subcategories of the map information?

Does the relative visual prominence of visual codings reflect their operational significance?

Has the visual balance of the map been preserved and if not, how could it be restored?

Do the codings conform with standard practice and are their meanings always compatible with the codings on other maps which users may encounter?

What use has been made of redundant and non-redundant codings, and is this compatible with known ergonomic coding principles?

Is there any coding which is illogical, such as using a large horizontal symbol to depict a vertical feature, and can this be justified on the grounds of clarity, operational significance, familiarity or convention?

Has the choice of each coding and method of portrayal taken adequate account of the evidence on how symbols should be portrayed for clarity and efficiency, in so far as this evidence is known to be applicable to maps?

Has the choice of pictorial, geometrical, abstract, alphanumeric, or other coding method been the most appropriate in the use of each information category and subcategory?

Do the chosen methods of portrayal adequately convey relationships between features?

Does all information remain readable when viewed in projected, CRT and combined displays?

Has adequate account been taken of knowledge on discriminability of brightnesses, contrasts, hues, line-widths, sizes, shapes and other psychophysical dimensions employed to draw distinctions on the map, so that the differences are always visible and their relative magnitudes accord with their operational importance?

Have the coding dimensions which are most efficient in psychophysical terms been chosen?

What alternative interpretations might the methods of coding lead to and are these of operational significance?

Does the map succeed in conveying correctly the accuracy of the information on it?

Are the methods of portrayal suitable for conveying how accurate the information is, and do these methods encourage the measurements which can be made accurately and discourage those which cannot?

Have the aesthetic attributes of maps been considered in the specification, and how important is it that they should be?

Is the density of the information on the map appropriate for the tasks and has the choice of codings been used successfully to manipulate the impression of density and clutter?

Are there any map features on which there is disagreement about their meaning?

Assessment

Is there agreement on the levels of task performance which are operationally acceptable, so that scoring criteria can be devised?

Is it possible to derive a representative range of tasks for map evaluation?

Is it possible to obtain a representative sample of mapping to be used in assessments, and to demonstrate that it is indeed representative?

Is it possible to derive samples of material for more specific evaluation purposes, such as testing the adequacy of portrayal of a designated feature?

What tasks must be included in a performance battery for use in evaluation of the map, and how should they be weighted?

What measures of performance are needed, and how should they be interpreted collectively?

Should subjective assessments be made, and if so, in what form?

What other measures – physiological, biochemical, descriptive, deductive, etc. – should be taken?

What further measures could be derived from, and related to, various theoretical concepts, such as information theory etc?

What criteria should be used to select measures, and to determine which theoretical frameworks may be apposite?

Is there a role for simplified maps, or for laboratory studies, and if so how may their practical relevance be demonstrated?

How are the users' needs assessed, and what is their relationship to what the user wants?

What relevant data can be gathered during flight, and how can such data be classified and interpreted?

In what concepts should the findings from experiments be expressed – the cartographer's, the user's, the human factors specialists's, the operational planner's, etc. – and how can the findings be made intelligible to others who are not fully familiar with whatever concepts are initially chosen?

How should the findings from evaluations be disseminated?

How can their validity and reliability be established?

What steps can be taken to ensure that findings which have been shown to be valid and reliable, are acted upon and lead to improvements in the map?

What criteria could be used to show that a map is not capable of further improvement?

CHAPTER 17

A POINT OF VIEW

17a REVIEW OF CURRENT KNOWLEDGE AND TECHNIQUES

The role of human factors in relation to aviation maps is still in the process of definition. Human factors knowledge gained in other contexts may apply to maps, but this must never be assumed. Some cartographic problems may ultimately be solved by innovative rather than standard human factors techniques. A few human factors problems in cartography may have no solution without compromising performance or objectives.

Human factors is a relatively new discipline. In principle, it can be applied to many activities and fields of endeavour. Its intelligent application requires a multidisciplinary approach, whereby the human factors specialist acquires a working knowledge of another discipline, the specialist in the other discipline studies human factors, or both work closely together in harmony. The application of human factors to cartography has been selective and sporadic. A logical plan of human factors contributions to cartography has not been systematically followed, for such a plan has never been made. A few geographers and cartographers have examined the psychological and human factors literature and have tried to apply what they have learned to maps, to be disillusioned on discovering that the firm and unequivocal recommendations stated in such sources do not possess the universal applicability they had been led to expect. A few psychologists and human factors specialists have tackled cartographic problems, and been disconcerted on encountering, in the processing and display of map information, problems of a complexity which their knowledge did not equip them to deal with. Those who have advocated most strongly that human factors principles should be applied to maps sometimes give the impression that they have never tried to obey their own exhortations, so unaware do they seem of the practical difficulties in doing so.

Advice on the need to design maps to meet users' requirements has also been proferred rather than heeded. Most cartographers still know little about how their maps are used. Most users do not know how maps are made, and this limits their ability to interpret the information on them. It does not necessarily follow from defining users' requirements that a map can be produced which will fulfil them, but it often seems to be implied that, if the users' needs could be successfully defined, other difficulties would melt away.

The amount of human factors research on aviation maps has hitherto been small, and many problems have not yet received serious study. The prospects of progress in the future are good, given adequate resources, funding and cartographic support. Many human factors issues which can bring major changes in map design and content have not yet been settled. When they have been studied, much specific work remains to be done. It is probably fair to claim that there is not a single human factors problem mentioned in this volume on which all the information needed for an optimum solution is known. For many problems, the extant data are scarcely sufficient to exclude gross human factors errors from the recommendations.

A few current difficulties can be traced to the long historical development of cartography which has led to the gradual evolution of many traditional cartographic practices, and to a cautious approach to innovations which may later prove to be transient or ill-founded. To some extent, cartography views human factors as such an innovation. The unwarranted overgeneralisation of some human factors recommendations has sometimes contributed towards a proper cartographic scepticism about the value of human factors evidence. The burden of proof does, and should, rest with human factors as a discipline to show its worth. The evidence on which human factors recommendations for maps are made must have universal applicability beyond dispute, or its applicability to maps must have been specifically demonstrated. It is counter-productive to presume that human factors recommendations for very simple information displays can be applied validly to maps, in the face of mounting evidence to the contrary. To persist in such an approach is initially futile and ultimately harmful.

Even when recommendations can be fully justified in human factors terms, there may be no practical means of implementing them because of constraints imposed by map production. It seems trite to expiate on the need for human factors recommendations to be compatible with map production technology, but past experience makes it clear that such fundamental advice is not superfluous, in that it has not always been followed in the past.

While it is reasonable for the cartographer to point out the problems of spurious locational accuracy of features portrayed on a map, it is equally reasonable for him to turn to human factors for advice on how features might be portrayed in order to indicate some uncertainty in their exact whereabouts. Currently, human factors has not solved this problem of how to indicate the quality and trustworthiness of information on maps or on other kinds of

information display, and therefore the solution to the problem must await further research. Human factors knowledge could be applied to the tasks, skills and physical environmental conditions appropriate for the compilation and the production of maps, as distinct from their usage, but this has not yet been done.

Although there is much general evidence on human limitations of perception, information processing, memory, orientation ability and other psychological processes relevant to map reading, little has been done to try and counter the effects of these limitations on map use. Two main approaches are possible. One is to design maps which acknowledge and compensate for known human limitations. The other is to explore how far selection, training, and instructions could circumvent these limitations. The feasibility of operational requirements and of the tasks which they imply must be assessed by relating the map content to the man's ability to make use of it. This is particularly important for future requirements where an attractive and advantageous innovation may reach an advanced stage of technical development before its cartographic or human factors consequences are recognised. When they are, they may pose difficulties which seem to be insuperable, or which require extensive experimentation before a solution can be found.

Some of the problems of aviation maps which in principle can be resolved with limited human factors resources are those associated with adapting maps to the cockpit environment. Problems which derive from cockpit lighting or vibration may prove to be more difficult to resolve, but those associated with handling, stowage, and the compatibility of maps with other job aids are less formidable. Methods for the indexing, retrieval, and restowage of maps after use, require a simple task analysis, and purpose-built stowage can be simply designed that is well integrated into the workspace. Perhaps of all topics associated with human factors and aviation maps, this is the most suited to the direct application of existing principles and knowledge. Any experimentation needed to verify the solutions proposed can be relatively simple, cheap and quick.

The efficacy of maps in the cockpit depends greatly on the compilation of adequate job descriptions, and the success with which their requirements have been incorporated in map specifications. There is no way of circumventing the detailed, thorough, painstaking effort which good job descriptions entail. They constitute a major commitment, but are fully justified as an improvement on the intuitive speculation which is otherwise the favoured basis for determining the needs of the map user. There is no substitute for job descriptions, and maps designed without them are likely to remain unsatisfactory in certain respects.

The map, being an information display, is intended to communicate information. It may look attractive, and its contents may be portrayed clearly, but these advantages convey no benefits if the map cannot be understood and related meaningfully to the user's task. To achieve this understanding, the map has to be designed to portray the information needed by the user for his tasks, and to meet the limitations of the user as an information processor and interpreter. Current knowledge is inadequate for these aims to be achieved fully now, but there is no reason in principle why they could not be achieved in the future. The cartographer needs a greater understanding of how visual information is interpreted by the user, and the human factors specialist should examine cartographic concepts such as visual balance in psychological terms.

Human factors, however, cannot affort to express its conclusions wholly in psychological terms, because the cartographer cannot be expected to translate psychological findings into cartographic practice. He has often attempted to do so in the past, and been misled by his lack of knowledge of the theoretical context and practical implications of psychological research. Therefore the conclusions from experiments on maps should be related to categories of cartographic information (e.g. roads, woodland, power transmission lines, railway stations), rather than to psychophysical dimensions (e.g. hue, value, chroma, line thickness, contrast, size). Allied to this is the role of human factors in determining what cartographic information is necessary for the user and indicating its relative operational significance by differences in visual coding. For some subcategories, the differences in meaning may be trivial for most operational functions, and it would be a mistake to make these subcategories more visually discriminable from each other than other subcategories with more operationally important differences in meaning. In this context, the job description has a vital role in distinguishing what is important from what is not. It is also necessary to recall that maps fulfil many functions outside the cockpit, such as briefing and route planning, in addition to those within it.

Investigations of the cockpit workspace include the consideration of maps in conjunction with various forms of collateral information without drawing conclusions about the information content of the map. Detailed studies of the compatibility of maps with other collateral information normally require the derivation of a map specification appropriate for the collateral material, since only the map can be modified to achieve a satisfactory match.

Technological innovations make new demands on cartography. Innovations affect directly the format, content or production of aviation maps. The advent of computer technology not only may demand drastic re-thinking of traditional cartographic methods and solutions, but call for equally drastic new approaches to the human factors problems which it brings.

The problem of the multiplicity of functions of each aviation map may be somewhat alleviated with advancing technology which offers some prospect of greater choice in the information displayed, by selective retrieval from a data bank. However a practical limitation on the grounds of cost is liable to remain for some time. A continuing operational limitation may be the problem of liaison between users performing different functions with different maps.

The accuracy of portrayal on the map should represent the optimum compromise between the operational needs for accuracy, the level of accuracy which the user can measure and judge at the scale, and cartographic accuracy inherent in the original data, compilation methods, and map production techniques. How to indicate the level of accuracy which should be attributed to the map information, how to make the best use of information at that level, and how to reconcile true map accuracy with the user's attributed level of accuracy, are human factors problems for which adequate solutions are not yet available, though they should not prove to be insuperable.

The attributes and abilities of a good cartographer are largely a matter of speculation. It may be that almost everyone possesses the potential to become a cartographer, but this seems very unlikely. Rather, a good cartographer is probably the product of certain fundamental abilities and appropriate training and experience. Flair may be another important characteristic of the good cartographer, but it cannot yet be described in psychological terms. It should be possible to achieve a better definition of cartographic abilities in the individual, and to optimise their development and use by training.

The attributes of the effective map user are almost as obscure as those of the good cartographer. Again, it seems implausible that map reading is an ability that all possess to an equal extent, or that everyone can be trained to read maps with equal facility. In aviation, it may seldom be practical to select users according to their map reading ability. Aircrew are generally selected because they possess other abilities, which may or may not be pertinent to map reading. Improvements in map reading skill must therefore rely on training rather than on selection. Currently there is insufficient knowledge to make confident proposals on how map readers should be trained, on how map reading relates to mental images of the environment or to geographic orientation, and on how important it is to make maps compatible with limitations on human information processing. These topics are amenable to human factors study.

Techniques for the investigation and analysis of map reading often have to be developed. There is a considerable body of evidence that the standard experimental methods for evaluating displays cannot validly be applied to maps, and that when the findings from such methods are used in map design they do not guarantee an efficient cartographic product. Perhaps it is in the conduct of experiments on maps, and in the application of the results of psychological research to maps, that the clearest demonstration is found that cartography and human factors do not share common concepts. For many cartographic concepts there is no psychological or human factors equivalent, and vice versa. The difficulties in proving new evaluation methods are formidable, but it is pointless to insist as a matter of principle that maps must be amenable to assessment by conventional psychological experimental methods, when often they are not. Such methods, if valid, are useful, but their validity has to be demonstrated, not presumed. It is important to draw on what is known about the perception of simple forms and complex patterns, design principles, the communication and processing of information, and other sources of relevant information, but these are sources of hypotheses and not of truths.

Human factors can be applied to most of the stages of map production and map use. At present, the main contribution is made towards the study of map use. Human factors has had little direct involvement in the determination of the specifications for existing map series and makes no contribution to map compilation and the interpretation of these specifictions by the cartographer responsible for preparing individual map sheets. Human factors expertise may be involved in identifying operational requirements and in carrying out job analyses from which decisions about specification changes can be derived. More typically, human factors is involved in the conduct of flight trials and laboratory experiments on map use in conjunction with aircraft avionics, displays and sensors. Otherwise, human factors expertise has often been limited to questionnaire design and evaluation and surveys of user opinion. Questionnaires are useful but they are restricted in the kinds of evidence that they can provide. Human factors research tends to show where maps are inadequate or fall short of operational requirements but fails to make positive recommendations for their improvement.

The general principles of human factors can be applied to aviation maps, as to any other subject matter. The general attributes of man can be related to map reading, as they can to any other activity. But specific methods and specific findings must be appraised anew in relation to maps.

17b FUTURE TRENDS AND PROBLEMS

If it could be assumed that maps in the future will remain substantially as they are now, the future human factors problems would generally be those which have already been identified. Recently however, there have been several intimations, particularly in the application of computers to cartography and in new display techniques, that many future maps may be radically different, in concept, design and purpose, from conventional paper maps, and that the human factors problems which they introduce will be new. The prospect is of more kinds of maps, generated in more ways, used for greater diversity of purposes, derived from digital data banks, produced selectively and quickly for specific operational roles – all requiring the contribution of human factors effort to realise their full potential and to meet operational needs. Such trends imply the extension of human factors advice beyond matters of portrayal to those of selectivity of data, retrieval of information, language and communication, memory and understanding.

Future mapping may be generated automatically for each mission and phase of flight, according to pre-programmed rules and mission classifications, in response to keyboard entries or direct voice inputs. Other sources of data may also

be available from navigation systems, from satellites, and from sensors in the aircraft or on the ground. Such information can be used to monitor present conditions, to compute command information, to predict future states, to relate these to terrain information and to guide the aircraft either automatically or by instructions to the pilot.

Whether future navigation systems will fulfil operational expectations and will have adequate human factors support is a matter of speculation. This will depend to a considerable extent on policy decisions about the role of man in advanced navigation systems, the consequent role of map displays, the allocation of human factors resources, the value of human factors contributions to map design, and the provision of appropriate cartographic support for human factors research.

Compared with the human factors resources which have been devoted to the design and evaluation of aircraft instruments and controls, the resources devoted to maps have been negligible. All advanced navigation systems have the weaknesses that the pilot can still become lost and have difficulty in reorienting himself. Apparently, a map can show the pilot where he is better than anything else, and for some tasks maps have proved to be essential. Cartographic information in some form will continue to be essential for navigation and guidance even in the presence of continuously generated collateral displays, and even for remotely piloted vehicles. At the very least the interpretation of such displays relies on cartographic support.

In human factors terms many aircraft instrument displays are simple and straightforward compared with maps, but these displays have attracted far more human factors effort. Despite the extensive literature cited in this volume the effort devoted to solving human factors problems related to aviation maps in particular, or to maps in general, is small when judged either by the importance of the topic or by the complexity of the problems. The future should therefore see greater human factors effort devoted to cartography in general, and the prospect of substantial operational benefits from such efforts. Designers of cockpit instrumentation can now draw on a large body of relevant human factors evidence, but designers of maps cannot. This imbalance should be remedied by a reallocation of human factors resources.

The role of human factors in relation to aviation is almost always inter-disciplinary, and aviation cartography is no exception. It will always be necessary to take account of the needs of the user and it will become more and more essential in the future to do so formally using orthodox techniques, such as compiling adequate job descriptions to be used as a basis for defining the nature and form of cartographic support. Inter-disciplinary work will also be necessary in relation to those who devise operational requirements and those who are concerned with engineering and technological developments which have cartographic implications. Most vital is the need for inter-disciplinary work with cartographers. It seems to be taken for granted that research on cockpit instrumentation requires extensive facilities such as a flight simulator and flight trials. It must be acknowledged that professional cartographic support is essential for valid human factors research on aviation maps so that experimental maps for evaluation can be produced to professional standards using representative techniques and materials. The lack of support in the past has resulted in human factors findings of dubious validity and generality, which have been difficult to interpret in cartographic terms.

A standard methodology for human factors evaluations of maps is not to hand and will have to be developed. Present methods represent a compromise between operational requirements, cartographic practicalities, and the principles of experimental psychology. The tasks of greater operational importance have not always been used in human factors evaluations. The use of symbol search and identification tasks in evaluation is administratively convenient, provides simple measures of task performance and allows findings to be linked to the psychological literature, but is not helpful in deciding how well a map can be correlated with the terrain, how well it facilitates route selection and tactical decision making or how well the information on the map could be communicated verbally. Batteries of representative tasks need to be derived which represent the range and relative importance of the operational functions of maps.

One consequence of the increased utilisation of digital computers is the emphasis on quantification, and the neglect of qualitative information. In the future, the greater facility to provide more specialised cartography will entail a better understanding of the requirements of different operational roles. More frequent revision of the representation of transient features should be possible, together with improvements in the classification and depiction of features based on their appearances from the air. Allied to this, there should be a more consistent application of the selection ratios for features in the compilation of maps at a given scale. The need for regionally specific relief representation as opposed to the rigid adherence to worldwide specifications must be reconciled with increased rationalisation and standardisation of the specifications for different scales. There are increasing demands for cartographic support for helicopter operations, which may lead to the provision of standardised 1:50,000 and 1:100,000 topographical maps on a worldwide basis.

The introduction of more formalised selection and training methods into cartography is desirable, with the main emphasis on selection for cartographers and on training for map users. Such developments will ensure increased knowledge of the relationship between visual imagery and map reading, and of the ability of users to memorise and recall cartographic information.

Future research on map design seems likely to be more concerned with the map as a whole and with the interactions between symbols rather than with the individual cartographic information or with symbols viewed in isolation. Psychophysical studies of the visual dimensions of map symbols have been popular in the past, but there is now increasing recognition of their inadequancies in predicting symbol perception in real map contexts. Research is needed on the central problems of map structure and visual organisation, on the complex interactions and relationships between

symbols, and on the factors affecting perceived information density and visual clutter. A coherent logic needs to be developed for deriving sets of symbols, which takes account of the relationships between them. Causal relationships between features should be represented by appropriate visual relationships between coding methods. Thus both in map design and in map evaluation, more effort is expected to be placed on viewing the map as a whole and on understanding the role of structural properties in map perception.

Both human factors and cartography have an extensive literature. Yet the amount of work which co-ordinates this literature across disciplines and integrates it is very small. It is not clear how far the requirements of each discipline can be reconciled, or how great the benefits would be in doing so. The initial applications of human factors in cartography have on the whole been fruitful when there has been an inter-disciplinary approach and adequate cartographic support. Aviation cartography is one field where major advances can be expected in the future. It is hoped that the information marshalled for this volume may foster fruitful collaboration between these two disciplines, for their mutual benefit and the benefit of the map user.

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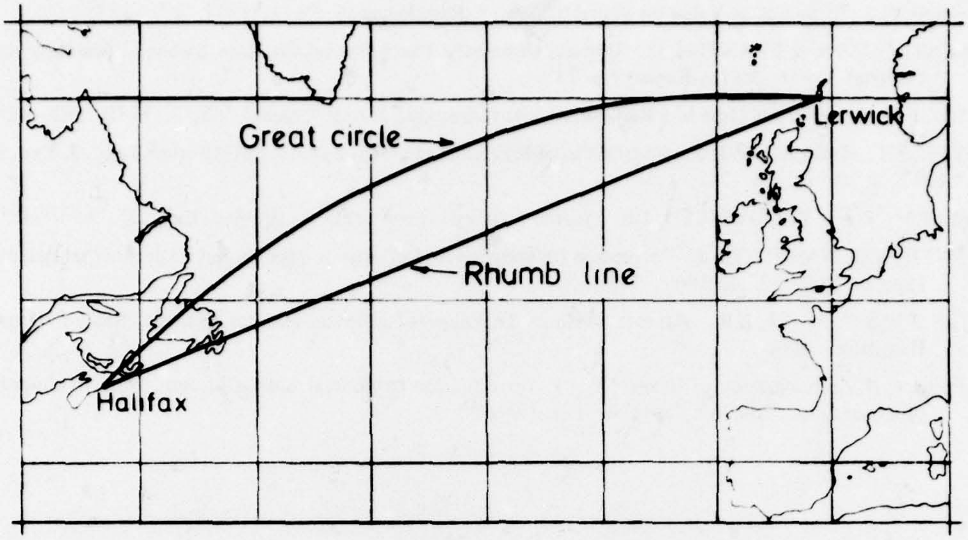

Fig.1 Great circle and rhumb line routes between Halifax and Lerwick on a Mercator Projection of the North Atlantic Ocean

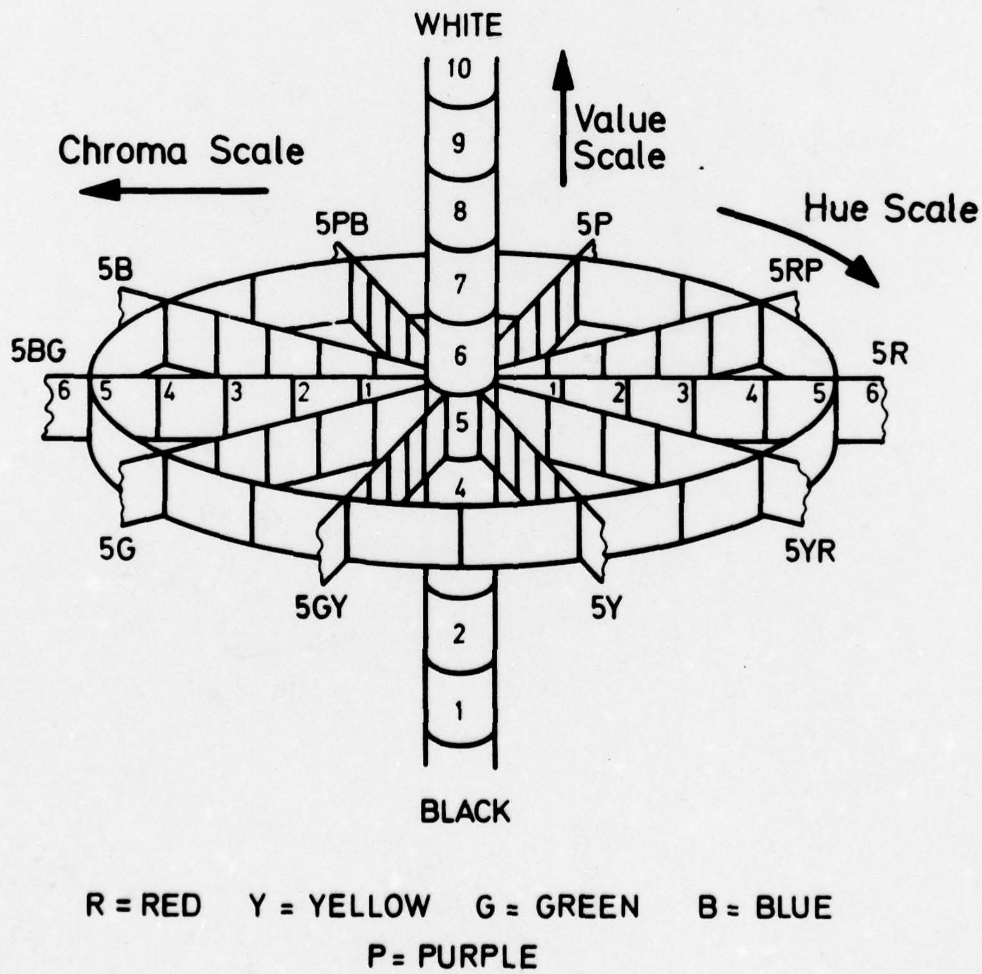

Fig.2 The Munsell colour space

INSTRUMENT NAVIGATION CHARTS	SCALE
En Route High Altitude	1" = 38.5 NM or 1:2,000,000–1:3,000,000
En Route Low Altitude	1" = 8–28 NM or 1:1,000,000–1:2,500,000
En Route Low/High Altitude	1:2,500,000–1:5,000,000
Decca and Dectrac Charts	1:50,000–1:500,000
VISUAL NAVIGATION CHARTS	**SCALE**
Operational Navigation Chart (ONC)	1:1,000,000
Tactical Pilotage Chart (TPC)	1:500,000
Low Flying Chart (LFC)	1:500,000
Joint Operations Graphic (JOG)	1:250,000

Fig.3 Air navigation charts

Name of facility	Abbreviation	Symbol
Basic radio facility symbol		
Non-directional radio beacon	NDB	
VHF omnidirectional radio range	VOR	
Distance measuring equipment	DME	
Collocated VOR and DME facilities	VOR/DME	
UHF tactical air navigation facility	TACAN	
Collocated VOR and TACAN facilities	VORTAC	

Fig.5 I.C.A.O. Standard symbols for radio facilities

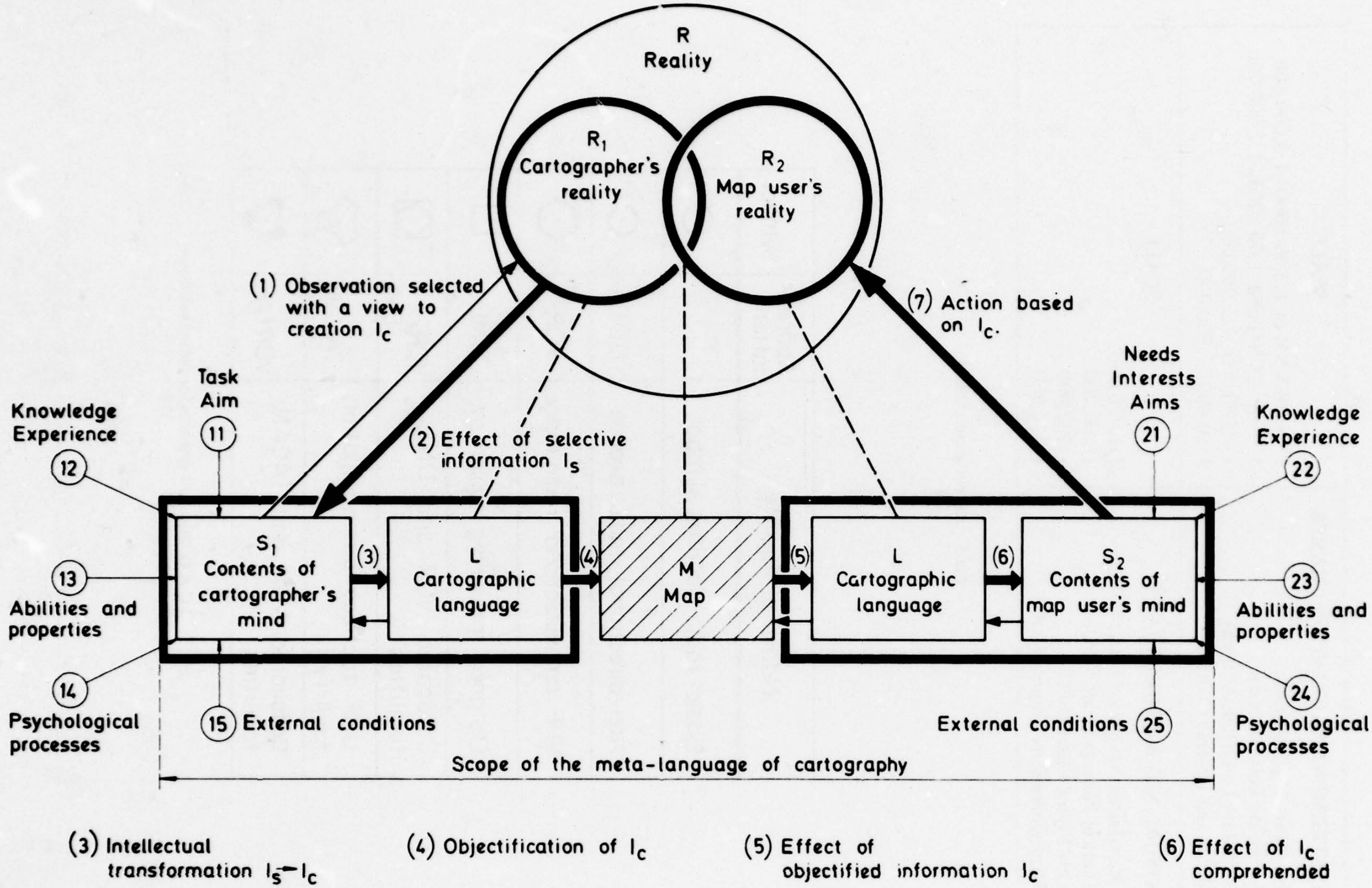

Fig.4 Kolacny's model of cartographic communication

INDEX OF AUTHORS' NAMES AND REFERENCE NUMBERS

APPENDIX

COLOUR PLATES 1 – 13

These colour reproductions were made by a four colour screened process, and therefore cannot always match exactly the colour variety or the colour processing of the original maps. However, they are a sufficiently close approximation to the originals to illustrate the human factors problems in aviation cartography to which they refer.

ONC
1:1,000,000

TPC
1:500,000

JOG
1:250,000

PLATE 1. Effects of scale and generalisation on the Operational Navigation Chart (ONC), Tactical Pilotage Chart (TPC) and Joint Operations Graphic (JOG).

PLATE 1

The functions of this world-wide "family" of topographical aviation maps are discussed in Chapter 4b of the text. As the map area reduces with the scale of representation the cartographer maintains legibility and accuracy and preserves the major characteristics of the region by the principles of cartographic generalisation – simplification (elimination, combination, exaggeration, displacement), symbolisation and classification. Aeronautical information remains relatively unchanged, altering the visual balance with topographical information to give greater prominence to aeronautical information at smaller scales. There is little evidence of a consistent approach to the application of colour coding.

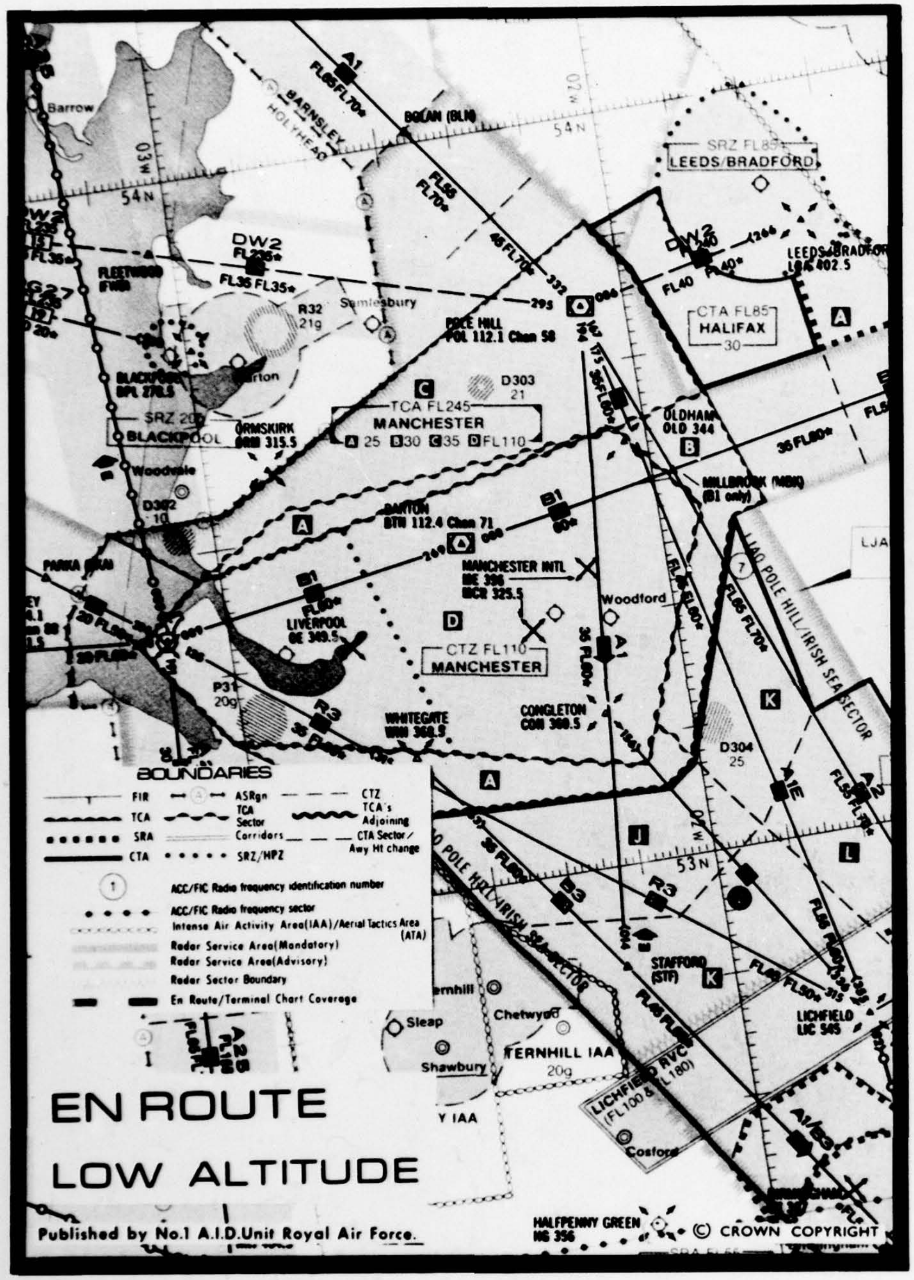

PLATE 2. RAF En Route Low Altitude Chart.

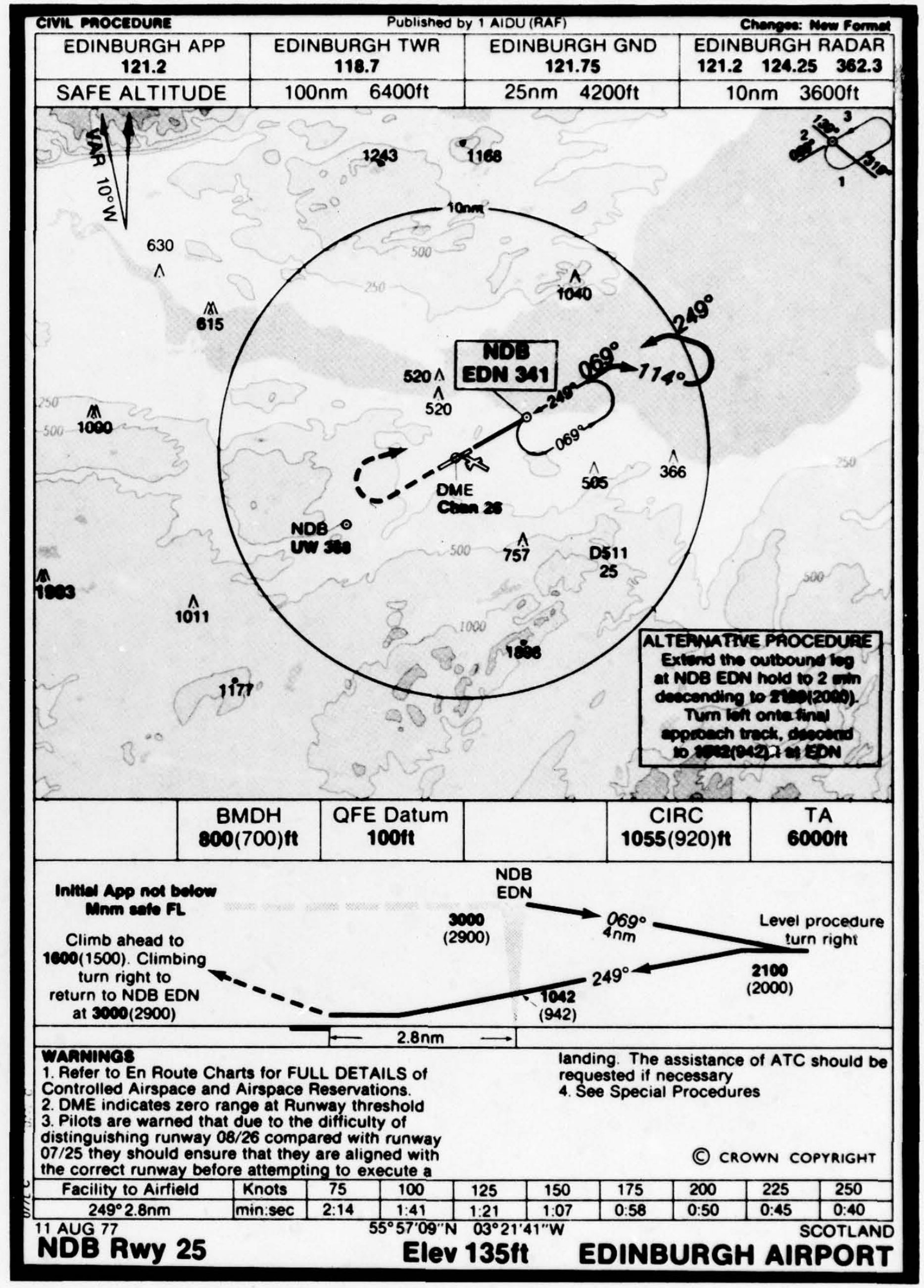

PLATE 3. RAF Terminal Approach Procedure Chart.

PLATE 2

Intended for en route instrument navigation in the lower and middle airspace, this chart shows airways information up to FL 250 (25,000 ft). Information on the upper air-space is shown on a separate chart (not illustrated). A monthly revision cycle is necessary to keep up with information changes and to reduce costs. Only four colour printing is used (black, grey, green, blue) and chart information is shown on both sides of the paper. A skeletal topographical base is provided for general orientation purposes (coastline, estuaries, lakes). The green area tint for routes and controlled airspace provides good figure-ground organisation but it reduces contrasts where lettering is most common, along airways. Seventeen classes of airspace boundaries are shown by varying the shape of line elements printed in grey and green. This is an excessive number of distinctions for abstract, geometrical coding methods and it is doubtful whether they can all be identified by users without reference to the chart legend.

PLATE 3

This chart gives all the information necessary for an approach to a runway using a specific *navigation aid, in this case* Runway 25, *Edinburgh Airport on non-directional beacon* (NDB) EDN 341. Horizontal and vertical views are given to the approach pattern, with warning notes on special features and times between the aid(s) and runway. In an earlier format, the airfield plan was also shown, but this now appears on a separate Landing Chart, increasing the space available and improving clarity and legibility. Coastlines and major hydrography are depicted for general orientation purposes. Obstructions and relief are shown for flight safety reasons. Contours and layer tints are a relatively recent addition. Previously only spot heights were shown but the high incidence of collision with high ground on approaches necessitated a more detailed terrain portrayal. Printing in only two colours (brown and black) is used in a relatively short revision cycle. More colours would be unlikely to improve legibility significantly with such an uncluttered chart. The size of the sheet is designed to be clipped into a small loose-leaf binder for easy reference.

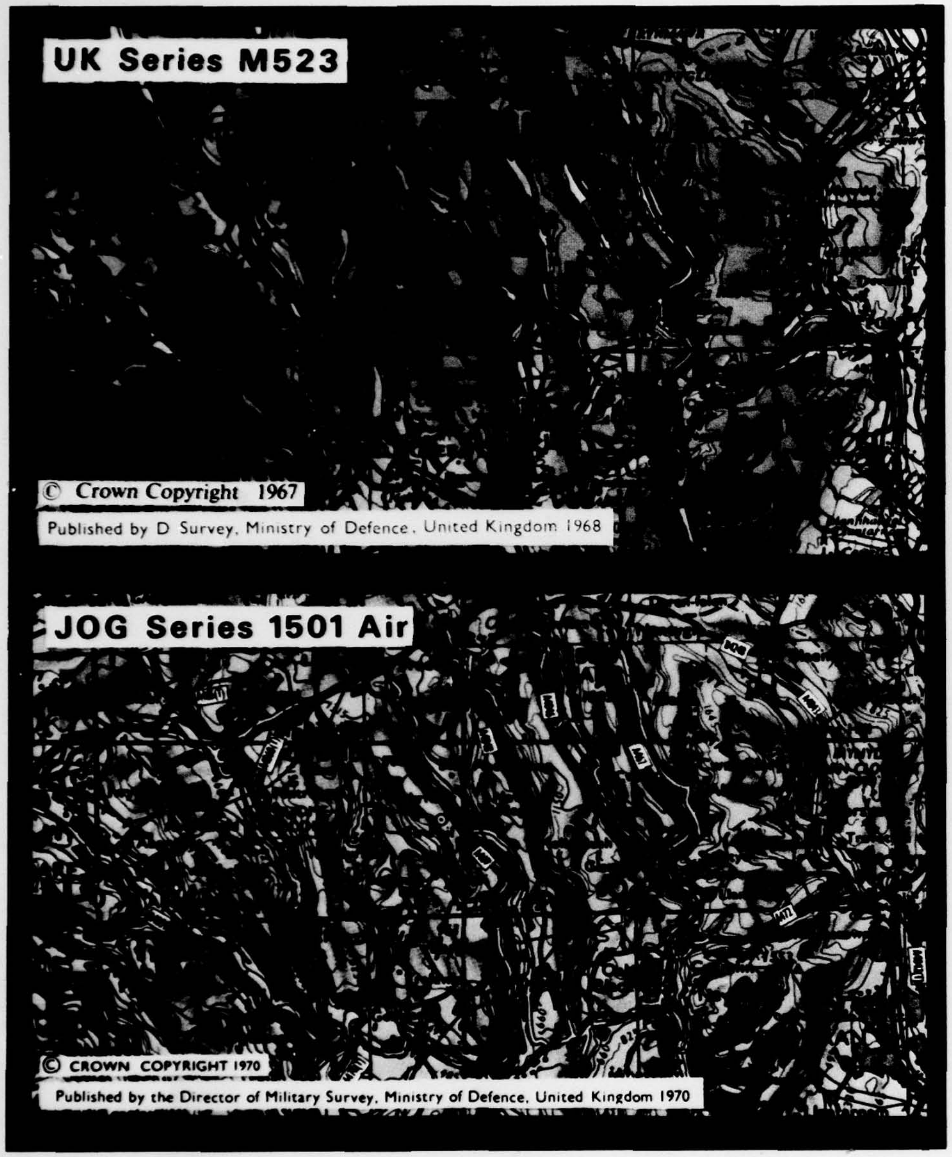

PLATE 4. Effects of information content and coding on visual clutter.

PLATE 5. Effects of colour coding on the legibility of built-up areas.

PLATE 4

Visual clutter is a major determinent of aircrew acceptability of 1:250,000 scale maps for visual navigation purposes.[222] The UK Series M523 and JOG Series 1501 Air have similar information content but coding differences make the latter appear generally more cluttered. The JOG colours are less saturated (lower chroma) and hue differences are smaller because the map is intended to be legible under red cockpit lighting. A greater range of type face is used on the M523 and most place names have smaller type sizes and stroke widths than on the JOG. High visual separability between code elements tends to reduce search time and decrease visual clutter.[580,641] The valleys of South Wales provide an exacting test of the efficacy of map specifications for representing relief and cultural information. Generalisation by displacement is necessary to discriminate communities and linear features in the valley floors (roads, railways and rivers). Too much displacement seriously interferes with the legibility of relief.

PLATE 5

Three TPC variants are shown to illustrate the problems of providing adequate legibility of overprinted information with different town in-fill colours. A conventional grey in-fill gives good brightness contrast for town boundaries against most backgrounds but it tends to desaturate overprinted colours, thereby reducing their conspicuity, and it gives poor brightness contrasts for symbols overprinted in black and electric-blue. Overprinted information has good brightness and colour contrasts against a yellow town in-fill, but the low brightness contrasts at town boundaries make shape perception difficult, particularly against buff-brown layer tints. Black casing is essential with yellow area tints, but the increased prominence of the casing relative to the in-fill causes undesirable line clutter. Magenta in-fill gives adequate colour and brightness contrasts at town boundaries, but the colour contrast of red overprinting is poor and its visual conspicuity is reduced, compared with the yellow in-fill. None of the examples provides a completely acceptable solution.

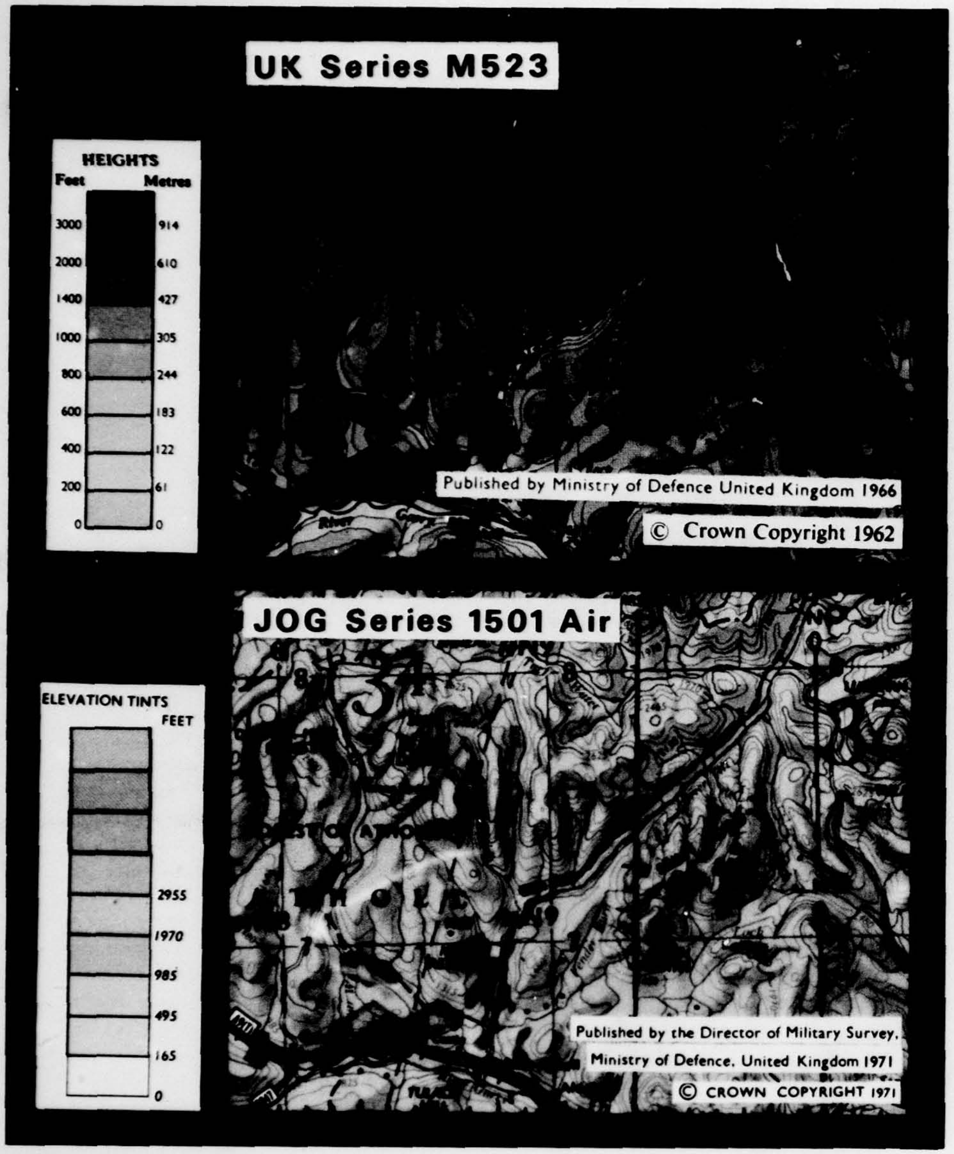

PLATE 6. Comparison of additively printed, continuous tone layer tints on the UK Series M523 and non-additive, irregular tints on the international Series 1501 Air, Joint Operations Graphic.

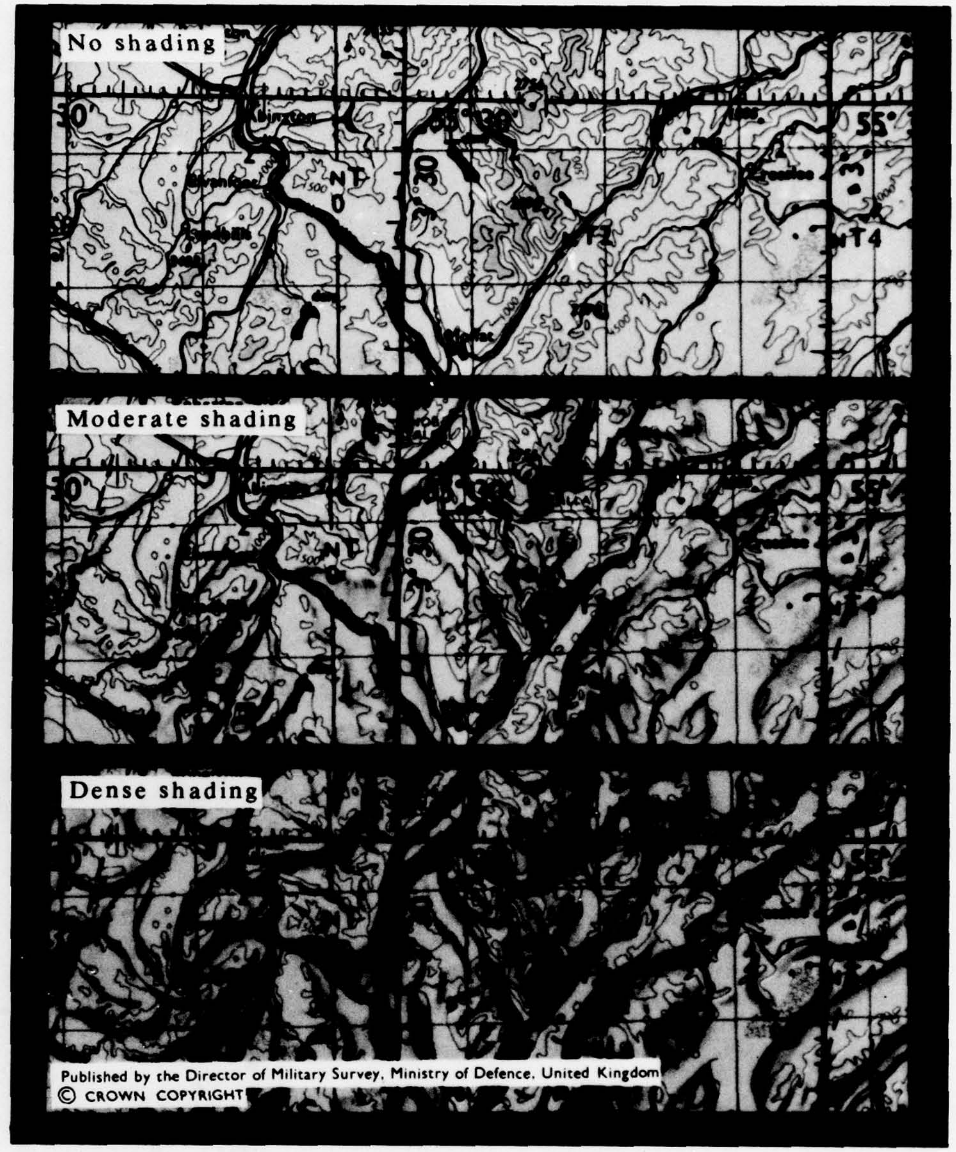

PLATE 7. Effects of density of hill shading on the legibility of relief.

PLATE 6

The scale of layer tints on the Series M523 is designed to show relative elevations in the UK. Thus, the relatively high mountains in the illustration are depicted in the full range of M523 colours. An additive printing technique is used whereby solids and screens of colours are printed over preceding colours to achieve a gradual colour transition with increasing elevation. The Series 1501 Air uses layers keyed to world-wide relief, printed non-additively, so that individual screens appear against a white, high reflectance background. International standardisation ensures uniformity between sheets but it does not necessarily provide optimal coding for individual regions.[402,640,641] The layers have an irregular progression and only the six lighter, lower colours are used for UK relief. This offers potentially higher contrasts for overprinting but the advantage is often lost by the presence of dark hill shading that is needed to achieve adequate terrain visualisation. Equal elevation intervals are used on the Series M523 up to 1,000 ft, and thereafter the intervals increase exponentially. The Series 1501 Air intervals increase exponentially throughout the scale. Ideally the size of the intervals should correspond to the relative operational significance of each elevation change.

PLATE 7

Hill shading provides visual cues to depth and shape by shading ridges and slopes as if the map were a three-dimensional model illuminated obliquely from the north-west. In the absence of shading, the map has a flat appearance and the shape of the terrain must be inferred from the pattern of contours, and layer boundaries. In theory, the density of shading should vary systematically with the orientation and steepness of the slope. High ridges should be shown by sharp contrasts and low valleys by gradual reductions in shading density. In practice, the shading is applied with considerable artistic licence and not according to strict geometrical principles. Erroneous impressions of terrain shape can easily be suggested by inappropriate shading. Dense shading may create an exaggerated impression of terrain coarseness and obscure other more reliable information, such as contours, against which the impression can be checked. The contrast requirements of overprinted information, such as spot heights, should limit the density of shading.

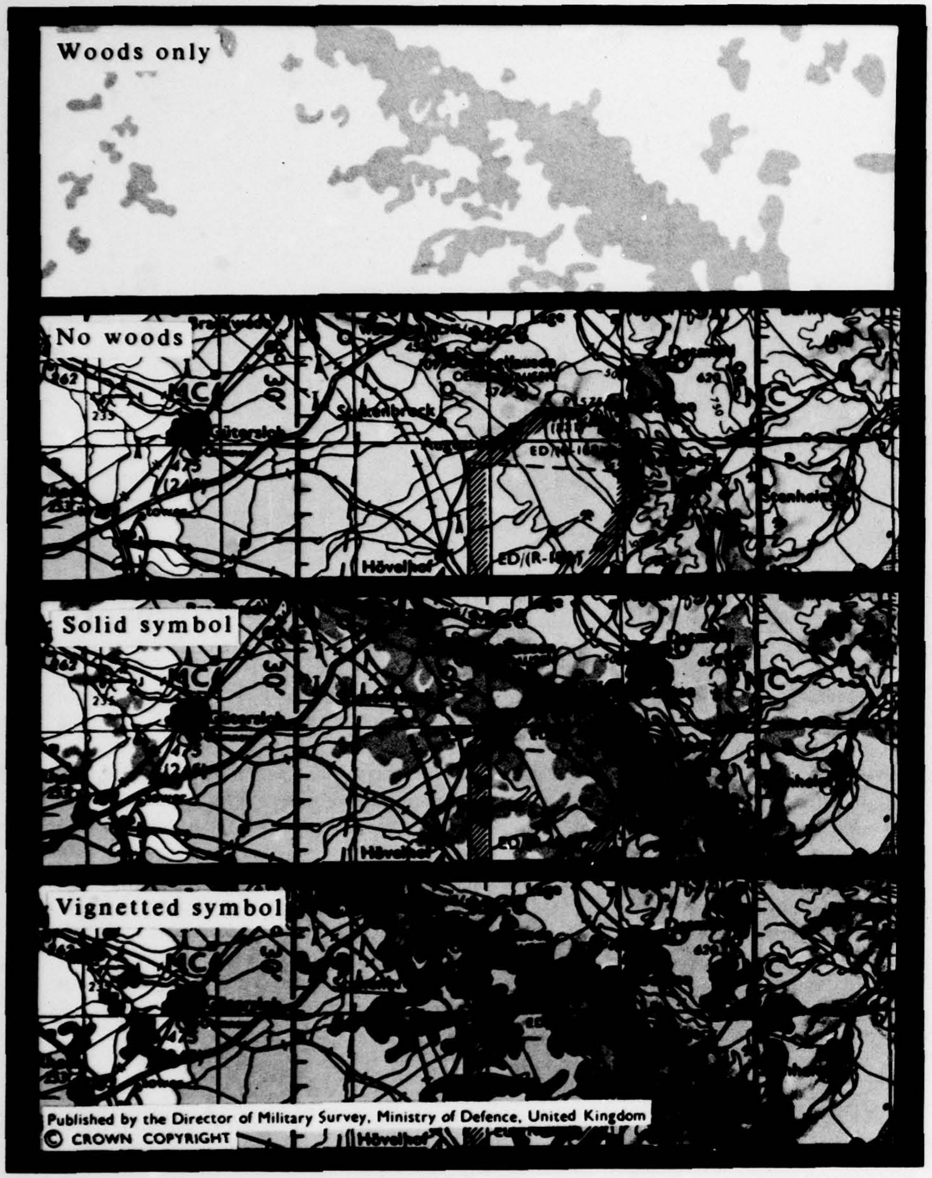

PLATE 8. Effects of solid and vignetted vegetation symbols on the legibility of woods and relief.

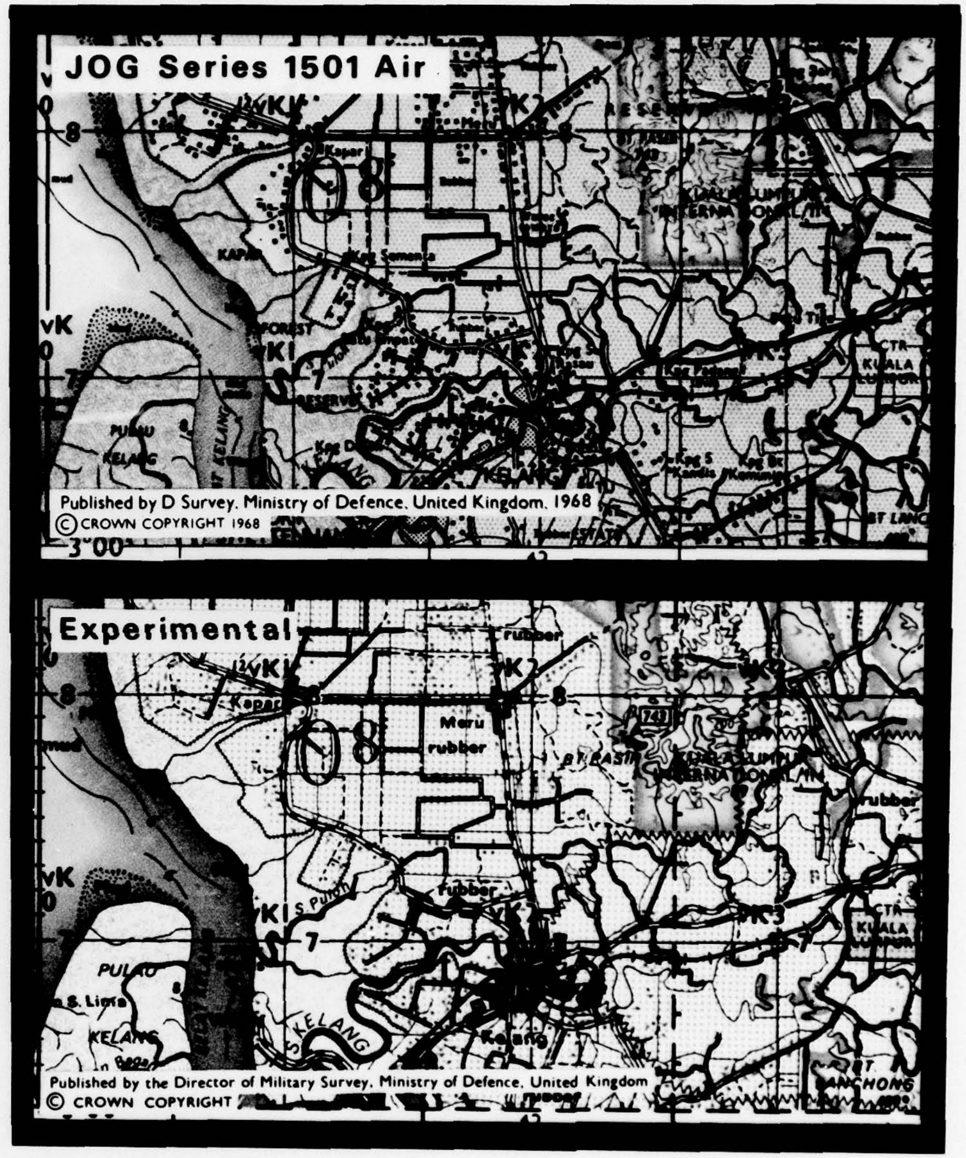

PLATE 9. Comparison of the 1:250,000 Joint Operations Graphic and an experimental sheet designed from human factors data.

PLATE 8

Overlapping distributions of area features are difficult to represent cartographically without adversely affecting their legibility. Woods and relief information are important for navigation at low altitudes. A woods plate and its corresponding topographical base are shown separately in the illustration and combined, using a solid green tint and a vignetted or banded vegetation symbol. The solid green symbol tends to flatten the relief by reducing contrasts of layer tints, contours and hill shading. A vignetted symbol offers a compromise by emphasing the woods boundaries and clearing the woods interior of green tint so that other topographical information retains its contrasts. Relatively small woods may appear in a solid tint depending on the width of the vignette band. Research has shown that vignetting reduces legibility, probably by increasing visual clutter, and that when the woods pattern is complex, woods shape recognition is difficult due to poor figure-ground orgainsation.[159] The fundamental incompatibility of woods and relief symbols is recognised in most map specifications by allowing woods to be omitted on high ground.

PLATE 9

The experimental sheet in the illustration was produced from Series 1501 Air repromats to test the applicability of human factors display principles to map design for moving map display applications.[70] Contrasts were maximised where information was densest by removing the first layer tint. Type sizes were increased, spot heights were boxed, pictorial symbology was introduced where possible. Shape coding was added to improve the discriminability of line features, town shapes were emphasised and coastlines were portrayed in accordance with their appearance from the air. Subsequent evaluation[100], using a symbol identification task, showed statistically significant improvements in map legibility under degraded (projected image) viewing conditions.

PLATE 10. Early (circa 1954) and present-day (TPC) 1:500,000 specifications designed to be legible under red cockpit lighting.

PLATE 11. Monochrome 1:50,000 helicopter tactical map, compiled from the *UK Series M726* and designed to be legible with image intensification, night vision goggles.

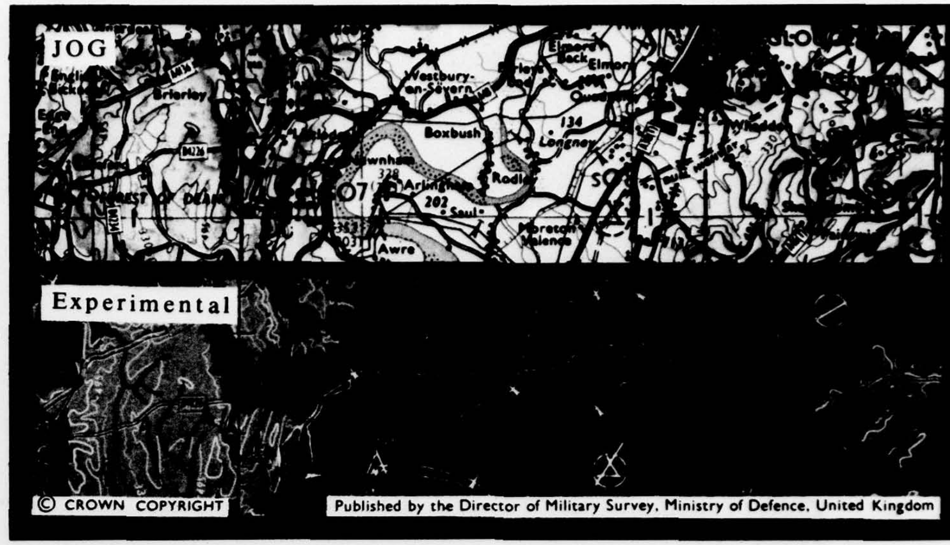

PLATE 12. Reverse format, 1:250,000 "black" map, based on the JOG intended to minimise transmitted light and maximise contrasts in combined radar and moving map displays.

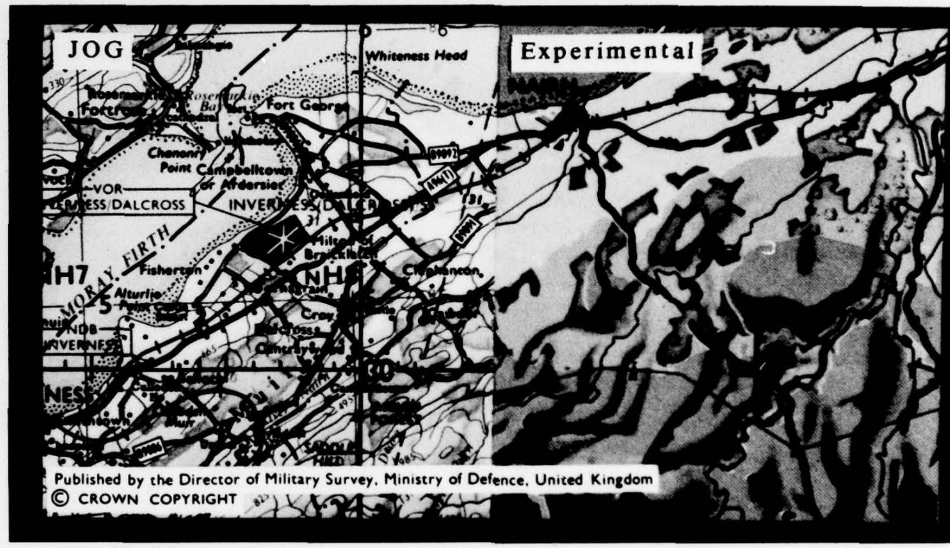

PLATE 13. Modified 1:250,000 JOG, with selective deletion and enhancement of features to facilitate radar map matching in combined radar and moving map displays.

PLATE 10

Red lighting is provided in many aircraft for internal cockpit tasks and intended to maintain the dark adaptation of the eye that is necessary for out-of-the-cockpit, night vision.[174] The illustration demonstrates the effects of red lighting on two maps designed to be read under these conditions. Under red light, colour discrimination is lost and map symbols can only be identified on the basis of achromatic coding variables (e.g. shape, size, lightness). Features shown in long wavelength colours (e.g. red, orange, yellow) lose contrast and disappear under red light. Features coded by medium and short wavelength colours (e.g. green, blue, purple) or colours with large grey/black components (e.g. dark brown) retain or increase in contrast under red light. Early RAF topographical maps, such as the Series 4072, used purple layer tints to retain relief legibility and roads were coded red because they were not visible on the ground under operational conditions. The current TPC specification chooses to retain the contrasts of roads by dark brown coding. Low ground is distinguished from high ground by a green/buff contrast boundary, and terrain shape is indicated by hill shading. The magenta town in-fill loses contrast and becomes illegible under red light.[657] Aeronautical information, shown in electric blue, remains visible on both maps. Recent research[348,411] indicates that red light legibility is no longer an important operational requirement.

PLATE 11

Image intensification, passive night vision goggles (PNGs) are used by helicopter aircrew during low level tactical operations at night. PNGs have a monochromatic response and poor resolution (1 milliradian) compared with the human eye (0.2 milliradian). Conventional 1:50,000 land mapping is not legible when viewed through the goggles. The experimental map shown in the illustration was designed for use with PNGs by the Plessey Company Ltd, Electronic Systems Research, under MOD (PE) contract,[129,406] using Ordnance Survey source material. A base map or underlay is provided from 1:25,000 mapping for flight planning, coloured red to disappear when viewed through the goggles, which have restricted chromatic response. Only a segment of the base map is shown. Features that are important for navigation and flight safety (e.g. pylons) are coloured black for PNG legibility and coded for identification by achromatic variables (e.g. shape, size, lightness). Three discriminable densities of grey area tint are used for woods, lakes and town in-fill. Direction of ground slope is indicated on the map by shading contour lines on the uphill side. Flight evaluations have produced favourable results.

PLATE 12

In combined radar and moving map displays (CRPMDs) the map image is optically combined with a forward-looking radar displayed on a CRT at the same scale as the map. This facility increases radar interpretability, facilitates early recognition of radar features and permits continuous monitoring of the accuracy of the navigation system. Conventional CRTs are not bright enough or persistent enough for viewing under high ambient cockpit illumination when combined with a bright map image. Field lens optical systems have been used to eliminate extraneous light by forming the primary image within the display.[376,414] Negative format, "black maps" were considered as a further means of increasing the contrasts of radar returns.[338] Black maps restricted transmitted light to features of radar significance and no light is transmitted through water features, for instance, because they give no radar returns. Landmass is shown in a contrasting grey because coastlines and river banks often show-up on radar. Built-up areas, airfields, obstructions and pylons give good radar returns in level terrain and these are coded in bright, high contrast colours. Negative formats have advantages at night when dark adaptation needs to be preserved, and the concept has been applied to helicopter tactical maps where reflected light from maps can disturb night vision, particularly when reflecting off the cockpit canopy.[404,406]

PLATE 13

In hilly and mountainous terrain, cultural features are often hidden from radar by relief and the main radar returns are from the relief itself, i.e. radar shadows, reflections from steep slopes, contrasts along ridge lines. Contour representation alone, as shown on the "black" map in Plate 12 proved unacceptable. Grey scale layer tints were added, using the principle "the lighter, the higher", but they failed to provide the vital textural and shape cues normally obtained from hill shading. Conventional hill shading is incompatible with a negative format. This realisation and the advent of brighter CRTs led to the development of conventional format CRPMD maps, shown in the illustration, with selective deletion and enhancement of features of radar significance.[338,345] Contours and spot heights are omitted to give a simplified relief presentation using only layer tints and hill shading, specially enhanced for radar-map matching purposes. Minor roads, isolated dwellings, grids, road numbering, and most place names are deleted because they are not relevant to the radar-map matching task. Major roads, obstructions and pylons are shown in high chroma red to maximise conspicuity.

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14. Abstract

The actual and potential contributions of human factors to the design and evaluation of aviation maps are described and assessed. The selection and depiction of map information are influenced by the tasks, by the users' and the cartographers' capabilities, and by technological advances. The relevance of psychological knowledge, particularly of visual perception and information processing, is appraised for map design, and methods and measures appropriate for the evaluation of maps are discussed. The skills and abilities of the successful map designer and the effective map user are considered. The communication of cartographic information in aviation could be enhanced by establishing which human factors data from other sources may validly be applied to map design and map reading.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD.

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